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EFFECT OF CATALYSTS AND pH ON STRENGTH OF RESIN-BONDED PLYWOOD

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SUMMARY

The effects of various catalysts used to cure the resinous adhesives on the strength properties of plywood was investigated, particularly with regard to the degree of acidity developed by the catalysts in the resin film and in the plywood. The flexural, impact, and shear strengths, both initially and after aging, of birch plywoods bonded with urea-formaldehyde and phenol-formaldehyde resins definitely decrease as the acidity of the plywood increases, as evidenced by a decrease in pH. Only in the case of plywood bonded with casein and urea-formaldehyde resins had the deterioration at the bond progressed sufficiently in the roof-aging tests to make it impossible to carry out strength tests because of delamination. A correlation between decrease in strength on aging of plywood bonded with alkali-catalyzed phenolic acid and increase in alkalinity of the panel was observed. Because of the different absorption capacities of the phenolic resins for acids and alkalies, it is not possible to predict the pH of the plywood panel from the pH of the resin film.

The susceptibility of birch wood, itself, to attack by acids and alkalies was determined in order better to understand the mechanism of the deterioration of resin-bonded plywood. A marked decrease in strength occurred when the pH of the wood was lowered below 2.0. In the range between pH 2.0 and 2.5, strong acids, such as hydrochloric and sulfuric, had a more pronounced deteriorating effect than weak acids, such as hypophosphorous and nitranilic. A marked decrease in strength of the birch also occurred when the pH was raised to 8.8 by the absorption of an alkali, tetraethanolammonium hydroxide.

INTRODUCTION

The increased use of resin-bonded plywood for structural parts of aircraft has made it necessary to determine the effect of various chemical properties of the resins on the strength properties of the resin bonds. Information of this nature is needed to utilize the materials properly in building satisfactory aircraft and to evaluate the causes of failure. Determination of the effect of acid and alkaline catalysts on the strength and aging properties of various types of resin bonds is one important phase of this work. This report presents the results of an investigation which was made to determine these relationships. Some of the data obtained in the early stages of the work were included in a preliminary report issued in 1943 (reference 1).

The degree of acidity or hydrogen ion concentration can conveniently be reported as a pH value which approximately is the logarithm of the reciprocal of the gram ionic hydrogen equivalents per liter; that is, $pH = \log 1/H^+$ per liter. Water has a concentration of H^+ ion of 10^{-7} and of OH^- ion of 10^{-7} moles per liter or a pH value of 7, and is said to be neutral in reaction. The presence of an acid in a water solution increases the concentration of hydrogen ions. Hence the concentration of hydrogen ions in an acid solution becomes 10^{-6} or 10^{-5}, or greater, and the pH value is less than 7. The presence of an alkali in a water solution increases the concentration of hydroxyl ions and decreases that of the hydrogen ions. Hence the concentration of hydrogen ions in an alkaline solution becomes 10^{-8}, 10^{-9}, or less, and the pH value is greater than 7. The product of the hydrogen ion concentration and the hydroxyl ion concentration is always equal to 10^{-14} in aqueous medium at 25° C. The pH value has been used throughout this report to indicate the degree of acidity of the various specimens.

The two most commonly used types of bonding agents in the manufacture of resin-bonded plywood are the phenol-formaldehyde and the urea-formaldehyde resins. Both types are cured either by the "hot-set" or the "cold-set" method. Since the demarcation between cold-set and hot-set bonding resins has not been definitely established in the industry, the resins used in this project were classified according to the temperature required to cure the resin in a commercially practical period of time, as follows:

Class R. These resins do not require a higher degree of heat for curing than that available at ordinary room or factory conditions.

Class M. These resins require a degree of heat greater than that available at room or factory conditions, but not over 160° F (71° C).

Class H. These resins require a temperature greater than 160° F (71° C).

In order to obtain a satisfactory degree of cure of class R and some class M resins, it is necessary with most of the commercial resins to use very active catalysts. One of the most active catalysts for curing these types of resins is the hydrogen ion which is usually expressed in terms of pH units when the concentration is less than one molar.

It is an established fact that wood deteriorates rapidly in acidic media. It is also known that urea-formaldehyde resins are not so resistant to acid conditions as are phenolic resins (see references 2 to 7). The work reported herein was designed to determine the effects of various catalysts and the pH of the resin bond on the strength properties of the resin-wood composite since the failures may be in the resin, in the wood, or in both resin and wood. It should be noted, however, that the acid conditions in the resin-bonded birch panels tested are attributable to the ingredients in the resin-glue mixtures and not to the wood or any extraneous source.

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MATERIALS

A group of adhesives which are being used to a great extent in the manufacture of resin-bonded plywood aircraft was selected for this work. These included urea-formaldehyde, phenol-formaldehyde, resorcinol-formaldehyde, furane, and unsaturated polyester resins and casein. The commercial designations and the manufacturers of the resins, and the classification of the various resins and resin-catalyst mixtures on the basis of the temperature required for curing, are given in table I.

Birch wood was used in the tests because it is the type most commonly employed in the manufacture of aircraft grade plywood in this country. Other woods were not investigated inasmuch as the primary objective of the investigation was the study of deteriorative effects characteristic of various resin-catalyst systems.

The test panels were made with sliced birch veneers carefully selected for straightness of grain and having an average thickness of 0.01 inch. The thin veneers were used to obtain a higher resin content than that normally used in aircraft plywood. Since the acidic conditions result from the resin, a high resin content would be expected to magnify the effect of the pH on the strength properties of the composite.

For the tests of the effect of the catalysts on the wood alone, sliced birch veneers 0.1 inch in thickness and specially selected for straightness of grain were used.

PREPARATION OF TEST PANELS

The resin glues were prepared according to directions received from the manufacturers and were applied to the birch veneers by means of rollers. This method produced resin films of uniform thickness on both sides of the veneers. The veneers coated with the class H resins were suspended from a drying rack and allowed to dry about 20 hours before assembling and pressing. The veneers coated with the class R and class M resins were assembled and pressed immediately after coating. Each panel consisted of 8 birch veneers arranged with the grain of plies 1, 3, 6, and 8 parallel to one another and with the grain of plies 2, 4, 5, and 7 perpendicular to the face plies.

In the early stages of the investigation the test panels were pressed at approximately 100 pounds per square inch, but this produced panels varying considerably in thickness and density. In order to obtain more uniform panels, stops 9 by 1 inch for use between the press platens were ground to a thickness of 0.075 ± 0.001 inch and the platens were ground to a flatness of 0.0001 inch. A load of 10 tons was applied to the platens.

The birch veneers used in each panel were conditioned by storage at 77° F (25° C) and 50 percent relative humidity, and were weighed before the resin coating was applied. The completed test panel was also conditioned and weighed. The resin content of the test panel was then calculated by means of the following equation:

Resin content in percent

$$= \frac{\text{Weight of test panel} - \text{Weight of conditioned veneers}}{\text{Weight of test panel}} \times 100$$

Three panel were prepared with each resin or resin-catalyst mixture. The conditions used to cure the panels, the average densities, and the average resin contents are given in table I.

TESTING PROCEDURES

Aging

Each test panel was cut into quarters and treated as follows:

1. One quarter section was not subjected to any aging treatment.

2. One quarter section was exposed continuously in Washington, D. C., (on the roof of the Industrial Building, National Bureau of Standards) on racks at an angle of 45° facing south for 1 year unless otherwise noted.

3. One quarter section was heated in a forced-draft oven at 176° F (80° C) for 40 hours.

4. One quarter section was subjected to a continuous oven-fog cyclic accelerated aging test. The cycle in this test consisted of the following:

Exposure Period (hr)	Temperature (° F)	(° C)	Relative Humidity (percent)	Apparatus
2	77	25	100	Fog cabinet
2	149	65	5	Forced-draft oven
2	77	25	100	Fog cabinet
18	149	65	5	Forced-draft oven

The sections were exposed for a total of 200 hours in the oven and 40 hours in the fog cabinet.

This latter test is a modification of the accelerated weathering test described in Federal Specification L-P-406a, Method No. 6021. Heating in an oven at 149° F (65° C) was substituted for the irradiation under the sun lamp prescribed in Method No. 6021 because the effect of the ultraviolet light would be expected to be negligible in the breakdown of the resin layer in plywood. The temperature to which the specimens are exposed is approximately 149° F (65° C) in both tests. The data in table II show that the decreases in flexural strength resulting from exposure of plywood specimens to the two tests, respectively, are practically identical.

Determination of pH

A thin film of the resins of class R and class M was cast on glass and allowed to dry for 20 hours at a temperature of 70° to 79° F (21° to 26° C). The resin film was then removed from the glass and ground to a fineness of 40 mesh. Two grams of the powdered resin were suspended in 10 milliliters of distilled water and the pH of the suspension was measure by means of a glass electrode after 15 minutes, and after 24, 48, 72, and 96 hours, or until the values were constant to within 0.05 pH unit.

Films were prepared from the class H resins by casting them upon a glass plate, using a knife blade to remove excess resin and make the thickness of the coating 0.02 inch or less. The cast films were placed in a circulating air oven at 149° F (65° C) until examination showed that most of the solvent had evaporated; this process required about 4 hours except in the case of Plaskon 107, which was cured after 3 hours at 149° F (65° C) and was not subjected to any further heating. This drying was followed by a cure in the oven at 300° F (149° C) until the films were hard and brittle, the latter operation requiring about 30 minutes. The hard, brittle films were pulverized in a small rock-crushing mortar and passed through a 40-mesh screen. The pH values of the powdered films were measured in the same manner as those of the class R and the class M films.

The acidity of the test panels was determined by grinding a portion of the panel to 40 mesh in a Wiley mill and suspending 1 gram of the powder in 5 milliliters of distilled water. The pH values of the water suspensions were usually constant after 48 hours.

The pH of the distilled water used in making the resin suspensions was 6.3. A few of the resin films and powered panels were also suspended in dilute hydrochloric acid solution of pH 4.5. The pH values of the acid suspensions are reported in table II and do not differ appreciably from those of the water suspensions. All the pH measurements were made at a temperature of 77° F (25° C) with a glass electrode. The measurements reported are accurate to ±0.05 pH unit.

Strength Properties

The test specimens for determining the strength properties were cut from the quarter sections after the aging treatments. The specimens were machined and then conditioned at 77° F (25° C) and 50 percent relative humidity for at least 48 hours prior to testing. All the tests were made at 77° F (25° C) and 50 percent relative humidity.

The flexural modulus of elasticity was measured on an Olsen Stiffness Tester, Tour-Marshall design. Specimens 5 inches long and 0.5 inch wide were cut from the panels. Two measurements were made on each specimen, one on each end. The test span was 2 inches long; the total bending moment applied to the specimen was 3 inch-pounds. The angular deflections were plotted against the bending moments and the deflection at a stress of 2500 pounds per square inch was determined from the curve. This stress was selected because the plots for all the samples were essentially straight lines up to that stress. The secant modulus of elasticity in flexure then was calculated from the approximate expression

$$E = \frac{229.2\ PL^2}{D\ a\ h^3} \tag{1}$$

where

E modulus of elasticity in flexure

P load

L length of beam

D deflection, degrees

a width of beam

h thickness of beam

This expression was derived from the formula for the deflection of a cantilever beam with a concentrated load at one end.

The flexural strength was measured on specimens 1.0 inch long and 0.75 inch wide cut from the panels. The specimen was supported on two parallel supports with a span of 5/8 inch. The load was applied at the center of the span by a pressure piece similar to the supports. The edges of the support pieces and of the pressure piece were rounded to 1/8-inch radius. The tests were made on a hydraulic testing machine with a head speed of 0.05 inch per minute. The machine was accurate to 2 percent of the lowest applied load. The flexural strength or modulus of rupture is calculated from the expression

$$F = \frac{3PL}{2\ a\ h^2} \tag{2}$$

where F is flexural strength and the other symbols have the same significance as in equation (1).

The impact tests were made on an Izod impact machine of 2 foot-pounds capacity. Specimens 2.5 inches long and 0.5 inch wide were cut from the panels.

The tensile tests were made according to Method No. 1011 of Federal Specification L-P-406. Type 1 specimens were used; the width of the reduced section was 0.5 inch. The tests were made on a hydraulic testing machine with self-alining Templin grips. The rate of head speed was 0.05-inch per minute.

Shear specimens 4 inches long and 0.75 inch wide were cut from the panels. A groove 1/8 inch wide and extending through approximately $4\frac{1}{2}$ veneers was milled on one face of the panel parallel to the 0.75-inch dimension. A similar groove was milled on the opposite face. The grooves on the specimens used in the preliminary tests were 1/2 inch apart, but, since many tensile failures were obtained, the distance between the grooves was reduced to 1/4 inch on the later specimens. The specimens were broken on a hydraulic testing machine at a rate of loading of 200 pounds per square inch per minute.

Delamination

One strip 0.5 inch wide cut from each quarter section of each test panel was subjected to a delamination test. The strips were placed in individual 3- by 20-centimeter test tubes which contained distilled water previously heated to the boiling point by immersion of the tubes in a water bath. The tubes containing the test strips were left in the bath of boiling water for 1 hour. On removal from the test tubes the specimens were immersed in water at 77° F (25° C) for 15 minutes and then dried at 140° F (60° C) in a forced-draft oven for 22 hours. This procedure constituted one cycle of the test. At the end of each cycle the test specimens were bent over a mandrel of 8-inch radius. After five cycles the specimens were bent over a 4-inch-radius mandrel. Observations regarding delamination were made.

Density

Density was determined by weighing and measuring machined specimens.

RESULTS OF TESTS

A preliminary investigation was made to obtain data for use in selecting the strength properties to be measured on all the test panels. Six panels were prepared with a phenol-formaldehyde resin (Tego film) and six with a urea-formaldehyde resin (Uformite 430 catalyzed with 10 percent ammonium chloride). These two materials were selected to determine the effects of high and low pH conditions, respectively. Specimens from each panel were tested unaged and after exposure to three aging tests. The strength properties measured in these preliminary tests were flexural modulus of elasticity, and flexural, impact, tensile, and shear strengths. The changes in these strength properties as a result of exposure to the aging conditions are given in table III.

On the basis of the results obtained in these preliminary tests, the size of the test specimens required, and an analysis of the stresses in the various tests, it was decided to employ the flexural, impact, and shear strengths for detecting the deterioration of the resin-bonded birch plywoods.

The detailed results of these tests are presented in tables IV, V, and VI and figures 5 to 12. The behavior of the materials with respect to delamination is shown in table VII. A summary of the effects of the catalysts on the strength properties of the panels bonded with urea-formaldehyde and phenol-formaldehyde resins is given in table VIII.

The specific effects of various acid and basic radicals present in catalysts used with phenolic resinous adhesives in the preparation of plywood were determined in a series of tests with known compounds. Panels were prepared with a resorcinol-formaldehyde resin (Penacolite G-1131) to which were added varying amounts of hydrochloric, nitric, sulfuric, phosphoric, hypophosphorous, trichloroacetic, benzenesulfonic, and nitranilic acids and sodium hydroxide. Titration curves of the resin with these acids and base are shown in figures 1 to 3. The flexural strengths of these panels, unaged and oven-fog-aged, are presented in table IX.

Similar experiments were performed with two phenol-formaldehyde resins. The titration curves obtained for one of these resins (Cascophen LT-67) with the acids and base are shown in figures 3 and 4. The results of the strength tests are given in table X.

In a further series of tests to determine the specific effect of the acid radicals present in commercial catalysts for resinous adhesives, three commercial catalysts were used, respectively, with three phenolic resins to prepare plywood panels. Four panels were prepared with each resin – one without catalyst, and one with each of the three catalysts, respectively. Only one of the resin-catalyst mixtures failed to cure satisfactorily at 150° F (66° C). The flexural strengths of these panels were determined before and after aging. The results of these tests are presented in table XI. Data are also given in table XI for one of the resin-catalyst mixtures in which the catalyst percentage was varied from 5 to 45 percent.

Proper interpretation of the data obtained in these experiments on the effects of various acid and alkaline catalysts on the strength of resin-bonded plywood required information on the effects of these chemicals on the wood itself. Accordingly, birch veneers of 0.1-inch thickness were immersed for 3 days in various concentrations of the same acids and alkalies used in the tests with the resins. The results of flexural strength measurements on the conditioned wood specimens are shown in table XII.

DISCUSSION OF RESULTS

Tests of Industrial Adhesives

Use of the various commercial resins with their catalysts selected for this investigation resulted in pH values for birch plywood ranging from 1.7 to 8.4. (See table I.) The ranges of pH for the test panels made from the various resins were as follows: Urea-formaldehyde, 1.9 to 5.7; phenol-formaldehyde, 1.7 to 8.4; resorcinol-formaldehyde, 4.8 to 6.3; and unsaturated polyester resins, 3.2 to 5.7.

The pH values of birch plywood were not affected by moderate baking or by exposure to cycles of heat and fog. This indicated that the acidic compounds determining the pH of the composite did not escape readily from the structure or did not react with the birch or its decomposition products in such a way that they lost their chemical identity. It would seem reasonable, therefore, to assume that the deterioration caused by pH would continue until failure occurred.

The results of the 240-hour oven-fog-aging test are in qualitative agreement with the results of the 1-year roof-aging test. An analysis of the data indicates that no quantitative statements can be made concerning the agreement. However, the 1-year roof-aging test was usually, but not always, more severe than the 240-hour oven-fog-aging test.

The effects of pH on the strength of the plywood prepared with the various commercial types of resins can best be reviewed by discussing the resins in three groups: urea, phenolic, and other resins.

(a) Urea Resins

The flexural, impact, and shear strengths of the urea-formaldehyde resin-bonded birch plywood depended markedly on the pH of the composite. This is shown by the data in tables IV, V, and VI and graphically in figures 5, 6, and 7.

The failure of the urea-formaldehyde resin-bonded materials in the delamination test is also affected by the pH of the plywood. The critical pH value in this test appears to be between 3.8 and 4.6 for both the unaged and the aged specimens.

Three of the panels with a low pH delaminated during exposure. This indicates that the loss in strength on roof aging can be attributed to both deterioration of the wood and deterioration of the resin.

(b) Phenolic Resins

An examination of the values in table VIII for the flexural, impact, and shear strengths of the phenolic resin-bonded panels shows that the presence of acid catalyst causes a decrease in these properties in the unaged panels in every case. This decrease was noticed especially with the panels prepared with the Catabond resins 590 and 200-CZ, wherein concentrated hydrochloric acid catalysts were used. It is well known that hydrochloric acid has a decidedly deleterious effect on most woods.

No failure of the phenolic resin-bonded composites occurred in the delamination test. The unaged and laboratory-aged specimens with pH values of 3.1 or less were brittle in the final flexibility test on the 4-inch mandrel. With one exception, those with pH values of 3.6 or more were flexible throughout this test.

(c) Other Resins

The remaining adhesives tested, which included resorcinol, furane, casein, and unsaturated polyester types, produced panels of pH 3.2 or greater, with the exception of the furane resin panel which had a pH of 2.2. These adhesives did not undergo marked deterioration in strength when subjected to the laboratory-aging tests. The pronounced reduction in strength which occurred under roof-aging conditions is attributable mainly to deterioration of the uncoated wood. However, the strengths of the roof-aged panels made with these resins were markedly inferior to those of the roof-aged panel made with the best phenol-formaldehyde resins. It is significant that, in the roof-aging tests conducted as part of this investigation, only in the case of the casein and some urea-formaldehyde glues had the breakdown at the bond progressed sufficiently to make strength tests on the roof-aged panels impossible.

Effect of Acidic and Basic Catalysts on Strength of Plywood

The outstanding feature of the experiments in which various acids and alkalies were added to the resorcinol-formaldehyde and phenol-formaldehyde resins (figs. 1 to 4) was their apparent absorption by the resin. Although relatively large amounts of the catalysts were added to produce resin solutions of low pH, the resin films and plywood panels had pH values considerably higher than those of their respective solutions.

The titration curves show that there is a definite chemical neutralization reaction between the phenolic type resins and acid and alkali, respectively. The amount of acid or acid-generating catalysts added to cure this type of resinous adhesive at room temperatures is generally greater than the neutral equivalent of the resin. Since this additional acid is not destroyed or is only loosely bound to the resin, it is free to cause deterioration of the materials in the structure.

The flexural strengths of the unaged panels made with the resorcinol-formaldehyde resin (table IX) did not undergo a significant decrease with increasing acidity of the resin solution. However, the oven-fog-aging conditions brought about a substantial reduction in strength which correlated with decrease in pH. Thus, although the pH of the unaged panels in many instances appeared to be beyond the critical acid range, the acid which had been absorbed by the resin was available to bring about deterioration of the panel under the aging conditions (fig. 8). The strong acids, such as hydrochloric, nitric, and sulfuric acids, had only slightly more deteriorating action than the weaker types, such as nitranilic and hypophosphorous acids (fig. 9).

An attempt was made to treat a phenol-formaldehyde resin, Cascophen LT-67, with the same series of acids used in the experiments with the resorcinol-formaldehyde resin. However, in the presence of hydrochloric, nitric, sulfuric, phosphoric, and nitranilic acids, the resin precipitated from solutions.

The results obtained with the weaker acids (table X and figs. 3, 4, 10, and 11) were comparable to those obtained with these same acids added to the resorcinol resin. When hypophosphorous acid was added to the resin solution in amounts sufficient to lower the pH of the plywood panel prepared with it to 2.2, a considerable decrease in flexural strength occurred in the oven-fog-aging tests. A similar effect was observed with another phenol-formaldehyde resin, Durez 12041. It is noteworthy that the flexural strengths of the unaged panels prepared with the phenol-formaldehyde resins were, in general, slightly higher than those of the resorcinol-formaldehyde panels.

The Cascophen LT-67 resin was also treated with various amounts of sodium hydroxide, a strong base. No evidence of significant deterioration in strength of the unaged plywood by relatively large amounts of the alkali was noted. However, there was some decrease in strength when the plywood was exposed to oven-fog-aging conditions. The decrease in strength correlated with increase in pH from an initial value of 6.4 for the aged panel without added alkali to 8.2 for the aged panel with the greatest amount of added alkali. Attempts were made to cure urea-formaldehyde resin adhesives at high pH values by the addition of alkali but were unsuccessful.

In general, the results shown in table XI and figures 12 and 13 for tests made with various commercial catalysts and resins show a correlation between the strength of the plywood and the pH of the unaged panels. The pH of the resin films prepared with these commercial resins, using the recommended amounts of the catalysts, were all less than 2.0 and it was not possible to predict from these values what the pH of the plywood panel would be. This is shown graphically in figure 13; similar graphs can be plotted from the other data in table XI.

Effect of Acids and Bases on Wood

The marked decrease in strength of the unaged plywood panels which resulted generally throughout the experiments reported herein when the pH of the panels was lowered by acid catalysts indicated that the wood was being attacked by the acids. The data in table XII and figure 14 indicate that both pH and catalyst radical have a part in this breakdown. Hydrochloric, benzenesulfonic, nitric, and sulfuric acids had the most pronounced deteriorating effect on the birch wood. Nitranilic and hypophosphorous acids had considerably less deteriorating action on the wood. This is particularly evident from a comparison of strengths for the birch veneers treated with the respective acids to produce pH conditions in the range 2.1 to 2.4. A marked decrease in strength occurred in every case when the pH of the birch veneers was lowered below pH 2.0 by treatment with the respective acids. The wood had a strong buffering action against alkalies. However, a pronounced decrease in strength occurred when the pH of the wood was raised to 8.8 by absorption of tetraethanolammonium hydroxide.

CONCLUSIONS

The flexural, impact, and shear strengths, both initially and after aging, of urea and phenolic resin-bonded birch plywoods are definitely affected by the pH. In the acid range, the lower the pH of the plywood panel, the poorer is the strength of the panel and its resistance to aging. The lower critical pH value, below which optimum strengths are not obtained and deterioration upon aging becomes appreciable, is approximately 4 for urea resin-bonded plywoods and 3.5 for phenolic resin-bonded plywoods.

The decrease in strength on aging of birch plywood bonded with a phenolic resin catalyzed with a strong alkali (sodium hydroxide) correlated with increase in pH of the plywood. The upper critical pH values, above which optimum strengths are not obtained and deterioration upon aging becomes appreciable, appears to be in the neighborhood of 8 for phenolic resins; the value for urea resin-bonded plywoods was not established because the resins would not cure at the high pH values.

The delamination of birch plywoods made with urea-formaldehyde resins is affected by the pH; in the acid range, the lower the pH, the fewer cycles required for delamination to occur. The delamination of birch plywoods made with phenolic resin is not affected by the pH; when the pH is less than 3.1, the materials are not so flexible as those with pH values of 3.6 or more. In 1-year roof-aging tests delamination occurred only in the case of plywood bonded with casein and with urea-formaldehyde resins containing acid catalysts which reduced the pH of the unaged panel to 3.4 or less.

At a given pH, strong acids, such as hydrochloric, nitric, and sulfuric acids, had only slightly greater deteriorating action on resorcinol-formaldehyde resin-bonded birch plywood than did the weaker types, such as hypophosphorous and nitranilic acids.

The pH values of the birch plywoods made with various resins are not markedly changed by moderate heating (40 hr at 80° C), by exposure to cycles of heat and fog or by exposure outdoors for 1 year.

Both pH and the nature of the acid radical have an effect on the deterioration of birch wood by acids. At a given pH weak acids have considerably less deteriorating action on the wood than do strong acids. A pronounced decrease in strength of birch wood occurred when the pH of birch wood was raised to 8.8 by absorption of tetraethanolammonium hydroxide.

National Bureau of Standards,
Washington, D. C., August 30, 1946.

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TABLE I.-DESCRIPTION OF RESINS AND RESIN-BONDED BIRCH PANELS

Commercial Designation of Resin	Manufacturer	Catalyst Added to Resin	Classification[a]	Conditions of Cure: Temperature (°F)	Conditions of Cure: Time (hr:min)	Density, Average (g/cm3)	Resin Content of Panels, Average (%)	pH: Resin Film	pH: Resin-Bonded Birch Plywood: Unaged	pH: Resin-Bonded Birch Plywood: Oven-Aged	pH: Resin-Bonded Birch Plywood: Oven-Fog-Aged	pH: Resin-Bonded Birch Plywood: Roof-Aged
A. Urea-Formaldehyde Resins												
Uformite 430	Resinous Products and Chemical Co.	10% Ammonium Chloride	R	Room	24:00	0.91	33	1.2	1.9	—	—	—
Uformite 430	Resinous Products and Chemical Co.	10% "Z"	R	Room	24:00	0.91	37	1.6	2.0	2.1	2.6	—
Uformite 430	Resinous Products and Chemical Co.	10% "Y"	R	Room	24:00	0.94	40	1.8	2.4	2.5	3.3	—
Plaskon 201-2	Plaskon Div., Libbey-Owens-Ford Glass Co.	2% "A"	R	Room	24:00	0.93	37	2.6	3.2	3.4	3.3	3.9
Casco 5	Casein Company of America	5% "AA"	R	Room	24:00	1.02	37	3.2	3.4	3.1	3.6	—
Plaskon 250-2	Plaskon Div., Libbey-Owens-Ford Glass Co.	Incorporated with resin	R	Room	24:00	0.84	34	3.4	3.6	3.4	3.6	3.3
Plaskon 107	Plaskon Div., Libbey-Owens-Ford Glass Co.	7% B-7	H	300	0:8	0.96	31	4.0	3.8	4.0	4.0	4.5
Uformite 500	Resinous Products and Chemical Co.	None	H	300	0:15	0.95	33	7.2	5.5	5.2	5.3	4.4
Casco 5	Casein Company of America	None	H	300	0:30	0.98	35	7.5	5.7	6.0	5.9	3.9
Uformite 430	Resinous Products and Chemical Co.	None	H	300	0:6	1.00	33	7.7	4.6	4.6	4.7	3.6
B. Urea-Resorcinol-Formaldehyde Resins												
Uformite 500	Resinous Products and Chemical Co.	20% Q 107; 0.7% Q 87	M	150	3:00	0.99	35	2.9	5.1	4.2	4.7	4.0
Plaskon 700-2	Plaskon Div., Libbey-Owens-Ford Glass Co.	16% Modifier	M	(Room (150	20:00) 3:00)	0.96	35	4.8	4.6	4.6	4.6	4.1
C. Phenol-Formaldehyde Resins												
Durez 12041	Durez Plastics and Chemicals, Inc.	10% 7422	M	150	24:00	0.97	36	1.4	1.8	1.8	1.9	2.6
Durez 11427	Durez Plastics and Chemicals, Inc.	10% 7422	M	150	24:00	1.04	39	1.4	1.8	1.8	1.9	2.6
Catabond 590	Catalin Corp.	11% Hydrochloric acid (27.8%)	M	(Room (150	24:00) 1:00)	0.90	37	1.6	1.7	2.0	2.3	3.1
Catabond 200 CZ	Catalin Corp.	11% Hydrochloric acid (27.8%)	M	(Room (150	24:00) 1:00)	0.91	37	1.6	1.8	2.1	2.4	2.8
Bakelite XO-3931	Bakelite Corp.	3% XK-2997	M	(Room (150	24:00) 2:00)	0.90	31	1.9	2.7	2.8	3.0	3.3
Bakelite XO-11749	Bakelite Corp.	45% XK-11753	R	Room	24:00	0.87	31	1.9	3.1	3.0	3.3	3.3
Catabond 590	Catalin Corp.	None	H	300	0:30	0.94	29	3.8	3.6	3.7	3.6	3.4
Bakelite XO-3931	Bakelite Corp.	None	H	300	0:30	0.97	35	5.5	4.5	4.7	4.5	3.5
Bakelite XO-11749	Bakelite Corp.	None	H	300	0:45	0.93	42	5.9	3.9	3.9	3.9	3.7
Catabond 200 CZ	Catalin Corp.	None	H	300	0:30	1.00	31	6.6	4.6	4.6	4.7	4.3
Cascophen LT-67	Casein Company of America	8% M-15	M	150	24:00	0.95	37	7.5	6.4	6.2	6.2	5.0
Durez 12041	Durez Plastics and Chemicals, Inc.	None	H	300	0:30	0.97	33	8.2	5.0	5.0	5.0	4.6
Bakelite BO-17540	Bakelite Corp.	15% BO-17545	M	150	24:00	0.94	21	9.2	7.3	—	7.3	—
Tego Film	Resinous Products and Chemical Co.	None	H	300	0:10	0.80	20	9.5	8.2	—	—	—
Amberlite PR-14	Resinous Products and Chemical Co.	Incorporated with resin	H	300	0:12	0.85	23	9.8	8.4	8.3	8.0	6.2
D. Resorcinol-Formaldehyde Resins												
Durez 12490	Durez Plastics and Chemicals, Inc.	30% Formaldehyde (37%)	R	Room	24:00	0.81	26	5.7	4.8	5.2	5.3	4.9
Penacolite G-1131	Pennsylvania Coal Products Co.	20% G-1131 B	R	Room	24:00	0.89	26	6.0	5.1	—	5.2	4.1
Bakelite XO-17613	Bakelite Corp.	20% XK-17618	M	150	24:00	0.97	28	6.2	4.8	—	4.6	—
Amberlite PR-75 B	Resinous Products and Chemical Co.	22% P-79	M	150	24:00	0.94	32	6.4	5.4	—	4.8	—
Penacolite G-1124	Pennsylvania Coal Products Co.	25% G-1124-B	R	Room	24:00	0.94	33	7.0	5.1	5.2	5.4	4.5
Durite S-3026	Durite Plastics, Inc.	16% 3026A	R	Room	24:00	0.86	22	7.5	6.3	—	6.0	—
E. Phenol-Resorcinol-Formaldehyde Resins												
Durez 12533	Durez Plastics and Chemicals, Inc.	100% 12534 B	M	150	24:00	0.94	38	6.6	5.1	5.5	5.4	5.0
F. Furane Resins												
Resin X	Plastics Industries Technical Institute	5% Z-1A	R	Room	24:00	1.00	28	1.7	2.2	—	2.3	2.6
G. Casein Glues												
Aircraft Joint P Glue	Casein Company of America	None	R	Room	24:00	0.88	34	12.0	8.4	7.8	8.0	—
H. Polymerization Resins												
Laminac	American Cyanamid Co.	1% Benzoyl Peroxide	H	125 300	0:30 0:15	0.83	26	2.4	5.7	3.9	3.8	3.4
Laminac	American Cyanamid Co.	1% Lauroyl Peroxide	H	125 300	0:30 0:15	0.81	24	2.8	4.0	4.0	4.0	3.5
MR-17-A2	Marco Chemical Co.	3% Benzoyl Peroxide	H	230	2:00	1.05	41	3.2	3.7	3.9	2.7	3.5
MR-17-B1	Marco Chemical Co.	3% Benzoyl Peroxide	M	230	2:00	1.01	39	3.4	3.2	3.3	2.6	3.5
Plaskon 900	Plaskon Div., Libbey-Owens-Ford Glass Co.	2% Benzoyl Peroxide	M	150	24:00	0.94	29	5.3	3.8	—	3.4	—
CR-39	Pittsburgh Plate Glass Co.	5% Benzoyl Peroxide	H	160	72:00	1.21	51	5.1	3.9	2.7	2.7	3.1

a. The resins are classified according to the temperature required to cure the resin. Class R includes those which cure quickly at room temperature. Class M includes those which require a temperature above room temperature but not over 160°F to cure. Class H includes those which require a temperature above 160°F to cure.

TABLE II.-EFFECT OF THE OVEN-FOG AND SUNLAMP-FOG AGING TESTS (240 HOURS) ON THE FLEXURAL STRENGTH OF RESIN-BONDED BIRCH PLYWOOD PANELS

Commercial Designation of Resin	Catalyst Added to Resin	Unaged Panel: Average pH	Unaged Panel: Flexural Strength (lb/in^2)	Oven-Fog-Aged Panel: Flexural Strength (lb/in^2)	Oven-Fog-Aged Panel: Loss Due to Aging (%)	Sunlamp-Fog-Aged Panel: Flexural Strength (lb/in^2)	Sunlamp-Fog-Aged Panel: Loss Due to Aging (%)
Bakelite XC-11749	None	4.8	27,600	22,200	19.6	21,900	20.6
do.	45% XK-11753	3.1	20,500	16,300	18.0	15,300	25.4
Catabond 590	None	3.5	28,100	21,700	22.8	22,100	21.4
do.	11% Hydro-chloric acid (27.8%)	1.8	15,600	10,800	30.8	11,000	29.5
Uformite 500	None	6.7	23,000	19,100	17.0	18,600	19.1
do.	10% Ammonium chloride	1.5	14,800	7,900	46.6	6,700	54.7

TABLE III.-CHANGES IN STRENGTH PROPERTIES OF BIRCH PLYWOODS CAUSED BY VARIOUS AGING METHODS

Property	Change for Panels Bonded with Phenolic Resin (Tego Film)			Change for Panels Bonded with Urea-Formaldehyde Resin (Uformite 430 with 10% Ammonium Chloride Catalyst)		
	Oven-Aged (%)	Oven-Fog-Aged (%)	Roof-Aged 6 months (%)	Oven-Aged (%)	Oven-Fog-Aged (%)	Roof-Aged 6 months (%)
Tensile strength						
Panel A	0	+ 3	+ 7	-14	-21	+19
Panel B	+ 7	+ 6	-11	-22	- 4	-42
Flexural strength						
Panel A	- 6	- 1	- 7	-15	-41	-53
Panel B	-12	+ 3	- 5	-10	-51	-72
Secant flexural modulus of elasticity (0 to 2500 lb/in.^{2})						
Panel A	-25	+12	-23	-15	0	-18
Panel B	-18	+17	-13	-25	0	- 2
Izod impact strength, flatwise						
Panel A	+36	+14	-26	-18	-38	-20
Panel B	0	-28	+38	-10	-27	+10
Izod impact strength, edgewise						
Panel A	+17	- 7	+17	-38	-50	+ 8
Panel B	-11	-18	-18	-15	- 6	+80
Shear strength						
Panel A	+11	-46	-33	- 5	-50	- 5
Panel B	-43	+70	-25	+ 5	-38	—

TABLE IV.—EFFECT OF CATALYST AND pH ON FLEXURAL STRENGTH OF RESIN-BONDED BIRCH PLYWOOD

Commercial Designation of Resin	Catalyst Added to Resin	Classification	pH of Unaged Panel	Unaged Panel: Flexural Strength Average (lb/in²)	Unaged Panel: Flexural Strength Range (lb/in²)	Unaged Panel: No. of Specimens	Oven-Aged Panel: Flexural Strength Average (lb/in²)	Oven-Aged Panel: Flexural Strength Range (lb/in²)	Oven-Aged Panel: No. of Specimens	Oven-Aged Panel: Change in Strength (%)	Oven-Fog-Aged Panel: Flexural Strength Average (lb/in²)	Oven-Fog-Aged Panel: Flexural Strength Range (lb/in²)	Oven-Fog-Aged Panel: No. of Specimens	Oven-Fog-Aged Panel: Change in Strength (%)	Roof-Aged Panel: Flexural Strength Average (lb/in²)	Roof-Aged Panel: Flexural Strength Range (lb/in²)	Roof-Aged Panel: No. of Specimens	Roof-Aged Panel: Change in Strength (%)
A. Urea-Formaldehyde Resins																		
Uformite 430	10% NH_4Cl	M	1.9	13,200	10,800-15,500	12	11,100	9,900-12,800	8	-16	7,400	5,600-9,400	16	-44	4,800[c]	2,800-6,200	6	-64
Uformite 430	10% "Z"	R	2.0	14,300	11,300-15,600	12	12,600	11,100-15,000	12	-12	10,100	7,800-12,200	12	-29	a	—	—	—
Uformite 430	10% "Y"	R	2.4	15,800	14,600-17,400	12	13,900	11,500-15,600	11	-12	12,600	9,600-14,200	11	-20	a	—	—	—
Plaskon 201-2	2% "A"	R	3.2	18,400	16,900-19,800	12	17,200	15,800-18,900	12	-7	15,100	12,300-17,700	12	-18	10,500	8,500-11,600	12	-43
Casco 5	5% "AA"	R	3.4	20,500	18,800-22,300	12	16,700	13,400-19,700	11	-19	15,700	12,200-20,700	12	-23	a	—	—	—
Plaskon 250-2	Incorporated with resin	R	3.6	19,000	17,100-19,600	12	16,700	12,800-19,600	12	-12	16,000	15,800-17,700	12	-16	9,900	8,400-11,400	12	-48
Plaskon 107	7% B-7	M	3.8	20,000	16,500-21,800	15	20,400	18,200-21,200	12	+2	17,200	16,000-20,400	12	-14	10,300	9,200-11,500	15	-49
Uformite 500	None	M	5.5	20,400	16,600-24,000	15	21,600	18,200-23,600	15	+6	17,600	11,800-19,100	11	-14	10,300	5,700-11,500	15	-50
Casco 5	None	H	6.7	23,100	19,300-26,600	13	23,000	19,600-25,600	15	-0.4	21,200	14,600-26,700	13	-8	11,300	8,000-13,700	15	-51
Uformite 430	None	H	4.6	22,700	20,700-25,700	15	22,800	19,500-27,400	15	+0.4	19,200	17,000-24,100	15	-15	11,800	5,800-13,900	15	-48
B. Urea-Resorcinol-Formaldehyde																		
Uformite 500	20% Q-107; 0.7% Q-67	M	5.1	19,100	16,400-22,500	12	21,400	17,600-25,400	12	+12	20,800	18,500-23,700	12	+9	11,000	9,000-12,400	12	-43
Plaskon 700-2	16% Modifier	M	4.6	21,800	20,500-23,400	12	22,900	20,300-25,700	12	+5	21,300	15,900-24,600	12	-2	16,000	14,000-18,000	12	-27
C. Phenol-Formaldehyde																		
Durez 12041	10% 7422	M	1.8	19,400	17,300-20,600	12	19,000	17,100-21,800	11	-2	13,500	10,100-15,300	12	-30	9,600	8,400-10,900	12	-51
Durez 11427	10% 7422	M	1.8	20,200	16,700-21,600	12	18,200	15,100-20,500	12	-10	11,400	9,900-13,900	12	-42	10,400	8,800-12,800	12	-49
Catabond 990	11% HCl acid (27.6%)	M	1.7	10,400	6,600-12,700	12	11,100	8,700-12,500	12	+5	9,300	7,700-11,600	12	-11	6,100	5,300-7,000	12	-42
Catabond 2000Z	11% HCl acid (27.6%)	M	1.8	11,700	8,600-17,400	12	13,100	10,800-15,900	12	+12	9,800	7,000-12,600	12	-16	6,600	5,700-9,500	12	-44
Bakelite XC-3931	7% XK-2997	M	2.7	17,300	15,200-19,800	12	16,200	10,600-20,000	12	-6	11,600	8,800-13,600	12	-33	9,800	8,900-11,900	12	-43
Bakelite XO-11749	45% XK-11753	R	3.1	18,400	15,400-19,700	12	17,700	12,500-23,100	12	-4	12,900	8,700-15,300	12	-30	9,800	6,000-11,400	12	-47
Catabond 590	None	M	3.6	24,000	21,300-25,800	15	26,700	23,400-29,700	15	+11	21,700	18,100-25,200	15	-10	17,000	14,800-19,000	10	-29
Bakelite XC-3931	None	H	6.5	23,600	18,100-30,000	15	25,100	22,900-28,900	15	+7	24,800	23,300-26,300	15	+5	10,700	9,100-12,800	15	-55
Bakelite XO-11749	None	R	3.9	24,600	22,100-26,800	15	27,900	23,300-29,700	12	+13	21,900	18,300-24,100	15	-11	14,200	11,500-16,000	15	-42
Catabond 2000Z	None	H	4.6	24,000	21,300-25,800	15	26,500	23,600-29,200	16	+10	25,000	19,900-27,300	15	+4	17,400	15,300-18,600	10	-28
Cascophen LT-67	8% M-18	M	6.4	21,900	17,600-24,200	12	25,400	21,700-27,100	12	+16	21,400	19,100-24,100	12	0	13,900	10,400-16,200	12	-37
Durez 12041	None	H	5.0	24,700	22,400-26,700	15	26,500	21,700-30,700	15	+8	23,800	21,300-27,100	15	-4	17,800	15,300-21,000	15	-28
Bakelite BC-17540	15% BC-17545	M	7.3	20,200	17,900-21,600	30	—	—	—	—	20,000	18,600-21,400	30	-1	12,800	10,800-14,200	30	-37
Tego Film	None	H	6.2	19,700	14,400-21,000	10	17,900	16,000-19,800	4	-9	17,500	13,900-21,700	8	-11	19,000[c]	14,300-20,700	12	-4
Amberlite PR-14	Incorporated with resin	M	8.4	21,800	16,000-25,300	15	22,600	20,100-25,600	15	+4	20,500	18,600-24,400	15	-6	13,400	8,500-16,400	15	-38
D. Resorcinol-Formaldehyde Resins																		
Durez 12490	11% Formaldehyde	R	4.8	17,500	15,400-19,100	12	19,600	17,600-21,000	12	+12	17,500	16,300-18,900	12	0	10,700	9,200-12,800	12	-39
Penacolite G-1131	80% G-1131B	R	5.1	19,200	17,100-21,800	36	—	—	—	—	21,600	19,800-23,100	36	+13	12,000	9,600-14,900	36	-38
Bakelite XC-17613	20% XK-17618	M	4.8	21,200	18,200-22,400	30	—	—	—	—	19,800	16,300-21,900	30	-7	12,800	10,700-14,300	28	-40
Amberlite PR-758	22% P-79	M	5.4	20,200	17,600-22,400	36	—	—	—	—	19,600	16,800-21,600	35	-3	11,000	9,800-12,700	32	-46
Penacolite G-1124	25% G-1124B	R	5.1	21,600	19,700-23,400	12	23,100	21,400-24,400	12	+7	18,000	16,100-19,400	11	-17	10,100	8,200-11,800	12	-53
Durite S-3026	16% 3026A	R	6.3	17,600	14,700-20,000	30	—	—	—	—	17,500	16,200-19,200	30	-0.6	10,700	9,800-11,900	30	-39
E. Phenol-Resorcinol-Formaldehyde Resins																		
Durez 12533	100% 12534B	M	5.1	22,300	21,100-23,800	12	23,400	21,400-26,000	12	+5	21,300	20,000-23,000	12	-5	10,700	9,400-12,800	12	-52
F. Furane Resins																		
Resin X	5% X-14	R	2.2	17,100	14,800-20,000	36	—	—	—	—	16,400	12,700-20,800	36	-5	8,500	7,000-10,800	36	-50
G. Casein Glues																		
Aircraft Joint P Glue	None	R	8.4	18,100	14,400-20,100	12	20,700	18,300-23,600	12	+14	17,800	12,700-18,600	12	-5	a	—	—	—
H. Unsaturated Polyester Resins																		
Laminac	1% Benzoyl Peroxide	M	3.7	15,300	12,700-18,900	13	19,600	18,400-23,300	15	+28	17,600	16,900-19,600	12	+16	9,900	9,400-10,800	10	-35
Laminac	1% Lauroyl Peroxide	M	4.0	18,600	17,000-21,000	15	19,500	18,000-20,700	15	+4	16,300	12,800-19,800	15	-13	9,500	9,000-10,600	15	-49
NR-17-A2	5% Benzoyl Peroxide	M	3.7	24,300	22,500-26,700	15	23,200	20,600-25,800	15	-5	20,900	17,900-23,700	14	-14	10,100	8,600-11,800	15	-58
BR-17-B1	5% Benzoyl Peroxide	M	5.2	22,900	20,800-26,100	15	22,400	19,700-27,000	15	-2	20,300	18,700-23,800	15	-11	9,700	8,900-11,300	15	-58
Plaskon 900	2% Benzoyl Peroxide	M	3.6	15,800	9,300-19,600	30	—	—	—	—	15,600	11,800-18,800	30	0	7,800	6,100-10,000	17[b]	-51
CR-39	5% Benzoyl Peroxide	M	3.9	24,600	21,500-27,100	20	23,600	20,900-26,700	15	-4	24,700	21,200-27,700	15	+0.4	12,300	10,500-14,000	15	-50

a. Panels delaminated during exposure on roof.
b. The three panels exposed delaminated partially so that only 17 specimens were obtained instead of 30 as planned.
c. Panels exposed on roof for only six months.

TABLE V.-EFFECT OF CATALYST AND pH ON THE IMPACT STRENGTH OF RESIN-BONDED BIRCH PLYWOOD

Commercial Designation of Resin	Catalyst Added to Resin	Classification	pH of Unaged Panel	Impact Strength (Edgewise): Unaged Panel			Oven-Aged Panel				Oven-Fog-Aged Panel				Reef-Aged Panel			
				Average (ft-lb)	Range (ft-lb)	No. of Specimens	Average (ft-lb)	Range (ft-lb)	No. of Specimens	Change in Strength (%)	Average (ft-lb)	Range (ft-lb)	No. of Specimens	Change in Strength (%)	Average (ft-lb)	Range (ft-lb)	No. of Specimens	Change in Strength (%)
A. Urea-Formaldehyde Resins																		
Uformite 430	10% Ammonium Chloride	R	1.9	2.0	1.4-2.5	12	1.4	1.2-1.6	8	-30	1.3	0.8-1.8	8	-35	3.0[b]	3.0-3.1	5	+50
Uformite 430	10% "X"	R	2.0	2.0	1.5-2.8	6	1.4	0.8-1.6	6	-30	1.2	0.9-1.6	6	-40	a	—	—	—
Uformite 430	10% "Y"	R	2.4	2.0	1.8-2.0	6	1.3	1.1-1.5	6	-35	1.5	1.4-1.8	6	-25	a	—	—	—
Plaskon 201-2	5% "A"	R	3.2	2.2	1.8-2.5	6	1.8	1.6-2.2	6	-18	1.8	1.1-3.0	6	-18	2.0	1.0-2.4	6	-9
Casco ?	9% "AA"	R	3.4	2.2	2.0-2.4	6	1.4	1.1-1.6	6	-36	1.7	1.5-1.9	6	-23	a	—	—	—
Plaskon 250-2	Incorporated with resin	R	3.6	2.2	1.8-2.8	6	1.6	1.4-1.8	6	-27	1.8	1.8-2.1	6	-18	2.4	1.7-2.8	6	+9
Plaskon 107	7% B-7	N	3.8	2.8	2.6-3.1	18	2.8	2.7-2.9	18	0	2.3	2.2-2.3	18	-18	1.9	1.4-1.9	18	-32
Uformite 500	None	N	5.5	2.9	2.1-3.6	18	2.9	2.4-4.5	18	0	2.4	2.3-2.4	18	-17	2.4	2.3-2.4	18	-17
Casco 5	None	N	5.7	3.0	3.0-3.2	15	2.8	2.7-3.0	13	-7	2.5	2.0-2.9	14	-17	2.6	1.8-3.1	14	-13
Uformite 430	None	N	4.6	3.0	2.8-3.3	18	2.6	2.5-2.9	18	-13	2.5	2.2-2.7	18	-17	1.9	1.8-2.0	18	-37
B. Urea-Resorcinol-Formaldehyde Resins																		
Uformite 500	20% Q-107; 0.7% Q-87	N	5.1	2.7	2.2-3.2	6	2.8	2.4-3.0	6	+4	1.9	1.6-2.2	3	-30	1.9	1.6-2.2	3	-30
Plaskon 700-2	10% Modifier	N	4.6	4.0	3.6-4.2	6	3.2	2.9-3.8	6	-20	2.5	2.1-2.7	6	-38	2.1	2.0-2.1	6	-48
C. Phenol-Formaldehyde Resins																		
Durez 12041	10% 7422	N	1.8	2.3	2.9-2.5	6	2.1	1.6-2.7	6	-9	1.6	1.2-1.8	5	-30	1.0	1.0-1.1	6	-57
Durez 11427	10% 7422	N	1.8	3.0	2.5-3.5	6	2.0	1.8-2.1	6	-33	1.3	0.9-2.0	6	-57	1.2	1.1-1.4	6	-60
Catabond 590	11% HCl acid (27.8%)	N	1.7	1.3	1.2-1.5	6	0.7	0.5-0.8	6	-46	0.8	0.7-0.9	6	-39	0.7	0.6-0.7	6	-46
Catabond 200-02	11% HCl acid (27.8%)	N	1.8	1.4	1.3-1.6	6	1.2	0.9-1.5	6	-14	1.1	0.9-1.2	6	-21	0.7	0.6-0.7	5	-50
Bakelite XO-3931	3% XK-2997	N	2.7	2.2	2.0-2.4	6	1.4	1.3-1.6	6	-36	1.5	1.4-1.5	6	-32	1.1	1.0-1.2	6	-50
Bakelite XO-11749	4% XK-11753	R	3.1	2.0	1.9-2.3	6	2.0	1.6-2.7	6	0	1.5	1.2-1.5	6	-25	1.2	0.6-1.9	6	-40
Catabond 590	None	N	3.6	3.4	3.2-3.6	17	3.4	3.3-3.5	18	0	2.9	2.8-3.1	18	-15	1.9	1.9-2.0	12	-44
Bakelite XC-3931	None	N	4.5	3.2	3.1-3.3	18	3.4	2.5-3.6	18	+6	2.8	2.7-3.0	18	-13	1.6	1.3-3.0	18	-50
Bakelite XO-11749	None	N	3.9	2.6	2.4-2.9	18	3.1	2.9-3.2	18	+19	2.5	2.1-2.9	18	-4	1.6	1.4-1.8	18	-38
Catabond 200-02	None	N	4.6	3.5	3.2-3.6	18	3.8	3.7-3.9	18	+9	3.0	3.0-3.1	18	-14	1.6	1.6-1.6	14	-54
Cascophen LT-67	8% M-18	N	6.4	2.7	2.4-3.0	6	2.6	1.9-3.9	6	-4	2.3	2.0-2.3	6	-15	2.1	1.5-2.8	6	-22
Durez 12041	None	N	5.0	3.3	3.1-3.4	18	3.4	3.3-3.5	18	-3	2.7	2.3-3.4	18	-18	2.0	1.9-2.2	16	-39
Tego Film	Incorporated with resin	N	8.2	3.0	2.4-3.7	23	2.8	2.6-3.0	8	-7	2.9	2.8-2.9	8	-3.3	2.9[b]	2.5-3.2	8	-3.3
Amberlite PR-14	Incorporated with resin	N	8.4	3.0	2.7-3.4	18	3.6	2.9-3.7	18	+20	3.0	2.9-3.2	16	0	2.2	2.2-2.2	18	-27
D. Resorcinol-Formaldehyde Resins																		
Durez 12490	30% Formaldehyde (37%)	R	4.8	3.3	3.0-3.4	6	3.1	2.5-3.5	6	-6	2.9	2.7-3.0	3	-12	2.9	2.7-3.0	3	-12
Pennacolite G-1124	25% G-11248	R	5.1	3.1	2.9-3.4	6	2.8	2.5-3.1	6	-10	3.3	2.3-4.5	6	+6	1.7	1.3-2.6	6	-45
E. Phenol-Resorcinol-Formaldehyde Resins																		
Durez 12533	100% 12534B	N	5.1	3.5	3.4-3.6	6	2.3	1.9-2.8	6	-34	2.3	2.0-2.6	6	-34	2.3	2.1-2.6	6	-34
F. Casein Glues																		
Aircraft Joint P Glue	None	N	8.4	5.0	4.8-6.1	6	3.9	3.6-4.1	6	-22	3.2	2.3-4.0	5	-36	a	—	—	—
G. Polymerization Resins																		
Laminac	1% Benzoyl Peroxide	N	3.7	3.9	3.7-4.2	18	4.0	3.8-4.1	18	+3	3.6	3.3-4.0	18	-8	1.9	1.9-2.0	12	-51
Laminac	1% Lauroyl Peroxide	N	4.0	4.7	4.4-5.1	18	4.8	3.5-5.8	18	+2	4.2	3.6-4.7	18	-11	2.1	1.6-2.7	18	-55
MR-17-A2	3% Benzoyl Peroxide	N	3.7	3.5	3.0-4.0	18	3.3	1.8-4.4	18	-6	3.2	3.1-3.3	18	-9	1.9	1.6-2.1	18	-46
MR-17-B1	3% Benzoyl Peroxide	N	3.2	4.6	4.3-4.8	18	4.0	3.4-4.6	18	-13	4.2	3.6-5.0	18	-9	2.4	2.4-2.5	18	-48
CR-39	5% Benzoyl Peroxide	N	3.5	3.8	3.3-4.1	18	4.2	3.5-4.6	24	+11	4.0	3.5-4.4	18	+5	2.9	2.5-3.7	18	-24

a. Panels delaminated during exposure on reef.

b. Panels exposed for only 6 months.

TABLE VI. EFFECT OF CATALYST AND pH ON THE SHEAR STRENGTH OF RESIN BONDED BIRCH PLYWOOD

Commercial Designation of Resin	Catalyst Added to Resin	Classification	pH of Unaged Panel	Shear Strength[a]: Unaged Panel, Average (lb/in²)	Unaged Panel, Range (lb/in²)	Unaged Panel, No. of Specimens	Oven-Aged Panel, Average (lb/in²)	Oven-Aged Panel, Range (lb/in²)	Oven-Aged Panel, No. of Specimens	Oven-Aged Panel, Change in Strength (%)	Oven-Fog-Aged Panel, Average (lb/in²)	Oven-Fog-Aged Panel, Range (lb/in²)	Oven-Fog-Aged Panel, No. of Specimens	Oven-Fog-Aged Panel, Change in Strength (%)	Roof-Aged Panel, Average (lb/in²)	Roof-Aged Panel, Range (lb/in²)	Roof-Aged Panel, No. of Specimens	Roof-Aged Panel, Change in Strength (%)
A. Urea-Formaldehyde Resins																		
Uformite 430	10% Ammonium Chloride	R	1.9	220	140-260	5	200	180-220	4	-9	130	120-130	3	-41	200	180-220	2[c]	-9
Uformite 430	10% "X"	R	2.0	440	430-500	4	400	390-420	3	-17	380	280-360	6	-33	b	—	-	—
Uformite 430	10% "Y"	R	2.4	580	520-640	5	450	435-470	2	-22	420	380-510	5	-28	b	—	-	—
Plaskon 201-2	2% "A"	R	3.2	620	560-670	5	550	—	1	-11	570	450-640	3	-8	540	500-640	6	-13
Casco 5	5% "AA"	R	3.4	600	530-670	4	700	—	1	+17	630	560-680	3	+5	b	—	-	—
Plaskon 250-2	Incorporated with resin	R	3.6	680	—	1	d	—	-	—	590	—	1	-13	480	430-520	4	-29
Plaskon 107	7% B-7	H	3.8	740	680-800	2	d	—	-	—	680	—	1	-8	540	450-640	6	-27
Uformite 500	None	H	5.5	740	680-810	2	d	—	-	—	710	690-720	2	-4	d	—	-	—
Casco 5	None	H	5.7	d	—	-	d	—	-	—	d	—	-	—	d	—	-	—
Uformite 430	None	H	6.6	820	720-880	4	790	—	1	—	d	—	-	-4	d	—	-	—
B. Urea-Resorcinol-Formaldehyde Resins																		
Uformite 500	20% Q-107; 0.7% Q-87	H	5.1	730	680-810	3	d	—	-	—	650	—	1	-11	620	600-630	2	-15
Plaskon 700-2	16% Modifier	H	4.6	810	780-830	3	750	—	1	-7	d	—	-	—	d	—	-	—
C. Phenol-Formaldehyde Resins																		
Durez 12041	10% 7422	H	1.8	d	—	-	d	—	-	—	d	—	-	—	d	—	-	—
Durez 11427	10% 7422	H	1.8	d	—	-	d	—	-	—	d	—	-	—	d	—	-	—
Catabond 590	11% HCl acid (27.8%)	H	1.7	d	—	-	d	—	-	—	d	—	-	—	d	—	-	—
Catabond 200-02	11% HCl acid (27.8%)	H	1.8	d	—	-	d	—	-	—	d	—	-	—	d	—	-	—
Bakelite XC-3931	3% XK-2997	R	2.7	640	—	1	580	570-590	2	-9	d	—	-	—	d	—	-	—
Bakelite XC-11749	4% XK-11753	R	3.1	390	370-410	2	570	—	1	+46	330	—	1	-15	d	—	-	—
Catabond 590	None	H	3.6	780	760-820	3	d	—	-	—	790	—	1	+1	d	—	-	—
Bakelite XC-3931	None	H	4.5	d	—	-	710	690-740	3	—	710	690-740	3	—	d	—	-	—
Bakelite XC-11749	None	H	3.9	750	700-820	4	700	590-760	4	-7	740	670-780	3	-1	d	—	-	—
Catabond 200 02	None	H	4.6	770	720-810	2	d	—	-	—	d	—	-	—	d	—	-	—
Cascophen LT-67	6% M-16	H	6.4	640	580-690	6	670	650-710	3	+6	780	770-800	2	+22	d	—	-	—
Durez 16041	None	H	5.0	750	640-830	4	840	790-890	2	+12	760	720-800	2	+1	d	—	-	—
Tego Film	Incorporated with resin	H	4.2	600	390-1200	6	450	420-580	4	-25	780	620-1030	4	+30	470	400-520	4[c]	-22
Amberlite PR-14	Incorporated with resin	H	6.4	770	660-930	5	d	—	-	—	730	440-1080	5	-5	600	380-750	3	-22
D. Resorcinol-Formaldehyde Resins																		
Durez 12490	30% formaldehyde (37%)	R	4.8	780	610-900	6	740	720-800	4	-5	610	530-680	5	-22	670	600-700	3	-14
Penacolite G-1124	25% G-1124B	R	5.1	870	860-870	3	820	740-900	2	-6	900	—	1	+3	d	—	-	—
E. Phenol-Resorcinol-Formaldehyde Resins																		
Durez 12533	100% 12534B	H	5.1	750	710-810	6	790	—	1	+4	700	670-700	3	-7	d	—	-	—
F. Casein Glues																		
Aircraft Joint P Glue	None	R	6.4	850	690-1040	6	860	—	-	+1	560	420-640	6	-34	b	—	-	—
G. Polymerization Resins																		
Laminac	3% Benzoyl Peroxide	H	3.7	520	280-640	6	540	490-600	6	+4	460	390-520	6	-12	500	470-540	4	-4
Laminac	2% Lauroyl Peroxide	H	4.0	500	470-590	6	450	390-500	6	-10	440	320-490	6	-12	420	390-440	6	-16
MR-17-A2	3% Benzoyl Peroxide	H	3.7	650	590-750	6	700	680-720	4	+8	650	600-740	5	0	d	—	-	—
MR-17-B1	3% Benzoyl Peroxide	H	3.2	700	670-770	6	780	670-750	4	0	730	690-780	5	+4	d	—	-	—
CR-39	5% Benzoyl Peroxide	H	3.9	870	660-960	6	830	710-900	3	-5	920	870-930	5	+6	d	—	-	—

a. Six specimens were tested in each case; those which broke in tension were not included in computing the shear strength.

b. Panels delaminated during exposure on roof.

c. Panels exposed for only 6 months.

d. All specimens broke in tension rather than shear.

TABLE VII.-EFFECT OF CATALYSTS AND pH ON THE DELAMINATION OF RESIN-BONDED BIRCH PLYWOOD

Commercial Designation of Resin	Catalyst Added to Resin	Classification	pH of Unaged Panel	Condition of Specimen After Delamination Test [a]: Unaged Panel	Oven-Aged Panel	Oven-Fog-Aged Panel	Roof-Aged Panel
A. Urea-Formaldehyde Resins							
Uformite 430	10% Ammonium Chloride	R	1.9				
Uformite 430	10% "Z"	R	2.0	D(1)	D(2)	D(1)	DR
Uformite 430	10% "Y"	R	2.4	D(1)	D(2)	D(2)	DR
Plaskon 201-2	2% "A"	R	3.2	D(3)	D(4)	D(3)	D(1)
Casco 5	5% "AA"	R	3.4	D(2)	D(2)	D(2)	DR
Plaskon 250-2	Incorporated with resin	R	3.6	D(2)	D(4)	D(2)	D(1)
Plaskon 107	7% B-7	H	3.8	D(3)	D(4)	D(3)	D(1)
Uformite 500	None	H	5.5	ND;F(5)	ND;F(5)	ND;F(5)	D(5)
Casco 5	None	H	5.7	SD(1);F(5)	D(1)	D(1)	D(1)
Uformite 430	None	H	4.6	SD(1);F(5)	SD(1);F(5)	SD(1);F(5)	D(5)
B. Urea-Resorcinol-Formaldehyde Resins							
Uformite 500	20% Q-107; 0.7% Q-87	M	5.1	ND;F(5)	ND;F(5)	ND;F(5)	D(5)
Plaskon 700-2	16% Modifier	M	4.6	ND;F(5)	ND;F(5)	ND;F(5)	D(5)
C. Phenol-Formaldehyde Resins							
Durez 12041	10% 7422	M	1.8	ND;B(5)	ND;B(5)	ND;B(5)	ND;B(5)
Durez 11427	10% 7422	M	1.8	ND;B(5)	ND;B(5)	ND;B(5)	ND;B(5)
Catabond 590	11% Hydrochloric acid (278%)	H	1.7	ND;B(5)	ND;B(5)	ND;B(5)	ND;B(5)
Catabond 200-CZ	11% Hydrochloric acid (278%)	M	1.8	ND;B(5)	ND;B(5)	ND;B(5)	ND;B(5)
Bakelite XC-3931	3% XK-2997	M	2.7	ND;B(5)	ND;B(5)	ND;B(5)	ND;B(5)
Bakelite XC-11749	45% XK-11753	R	3.1	ND;B(5)	ND;B(5)	ND;B(5)	ND;B(5)
Catabond 590	None	H	3.6	ND;F(5)	ND;F(5)	ND;F(5)	ND;B(5)
Bakelite XC-3931	None	H	4.5	ND;F(5)	ND;F(5)	ND;F(5)	ND;B(5)
Bakelite XC-11749	None	H	3.9	ND;F(5)	ND;F(5)	ND;F(5)	ND;B(5)
Catabond 200-CZ	None	H	4.6	ND;F(5)	ND;F(5)	ND;F(5)	ND;B(5)
Cascophen LT-67	8% M-18	M	6.4	ND;F(5)	ND;F(5)	ND;B(5)	ND;B(5)
Durez 12041	None	H	5.0	ND;F(5)	ND;F(5)	ND;F(5)	ND;B(5)
Tego Film	Incorporated with resin	H	8.2				
Amberlite PR-14	Incorporated with resin	H	8.4	ND;F(5)	ND;F(5)	ND;F(5)	ND;B(5)
D. Resorcinol-Formaldehyde Resins							
Durez 12490	30% Formaldehyde (37%)	R	4.8	ND;F(5)	ND;F(5)	ND;F(5)	ND;B(5)
Penacolite G-1124	25% G-1124 B	R	5.1	ND;F(5); W	ND;F(5); W	ND;F(5); W	ND;B(5); W
E. Phenol-Resorcinol-Formaldehyde Resins							
Durez 12533	100% 12534 B	M	5.1	ND;F(5)	ND;F(5)	ND;F(5)	ND;B(5)
F. Casein Glues							
Aircraft Joint P Glue	None	R	8.4	ND;F(5); W	ND;F(5); W	ND;F(5); W	DR
G. Polymerization Resins							
Laminac	1% Benzoyl Peroxide	H	3.7	SD(1);F(5)	SD(1);F(5)	SD(1);F(5)	SD(5);F(5)
Laminac	1% Lauroyl Peroxide	H	4.0	SD(1);F(5)	SD(1);F(5)	SD(1);F(5)	SD(5);F(5)
MR-17-A2	3% Benzoyl Peroxide	H	3.7	ND;F(5)	ND;F(5)	ND;F(5)	SD(5);F(5)
MR-17-B1	3% Benzoyl Peroxide	H	3.2	ND;F(5)	ND;F(5)	ND;F(5)	SD(5);F(5)
CR-39	5% Benzoyl Peroxide	H	3.9	ND;F(5)	ND;F(5)	ND;F(5)	SD(5);F(5)

[a]The specimens were subjected to 5 cycles of immersion in boiling water and drying, described on page 8. Figure in parenthesis refers to cycle in which observation was made. Abbreviations are as follows:

D = delaminated
SD = slightly delaminated
ND = no delamination
DR = delaminated during exposure treatment on roof
W = warped
B = brittle
F = flexible

TABLE VIII.- EFFECT OF CATALYST AND pH ON FLEXURAL, IMPACT, AND SHEAR STRENGTHS OF RESIN-BONDED BIRCH PLYWOOD

Commercial Designation of Resin	Catalyst Added to Resin	pH of Unaged Panel	Decrease in Flexural Strength[a] Unaged Panel (%)	Oven-Aged Panel (%)	Oven-Fog-Aged Panel (%)	Roof-Aged Panel (%)	Decrease in Izod Impact Strength[a] Unaged Panel (%)	Oven-Aged Panel (%)	Oven-Fog-Aged Panel (%)	Roof-Aged Panel (%)	Decrease in Shear Strength[a] Unaged Panel (%)	Oven-Aged Panel (%)	Oven-Fog-Aged Panel (%)	Roof-Aged Panel (%)
A. Urea-Formaldehyde														
Uformite 430	None	4.6	—	—	—	—	—	—	—	—	—	—	—	—
	10% "Y"	2.4	30	39	34	b	33	50	40	b	29	43	c	c
	10% "Z"	2.0	37	45	47	b	33	46	52	b	41	49	c	c
	10% NH Cl	1.9	42	51	61	b	33	46	48	b	73	75	c	c
Casco 5	None	5.7	—	—	—	—	—	—	—	—	—	—	—	—
	5% "AA"	3.4	11	27	26	b	27	50	32	b	c	c	c	c
B. Phenolic Resins														
Catabond 590	None	3.6	—	—	—	—	—	—	—	—	—	—	—	—
	11% HCl acid (27.8%)	1.7	56	58	57	64	62	79	72	63	c	c	c	c
Catabond 200-CZ	None	4.6	—	—	—	—	—	—	—	—	—	—	—	—
	11% HCl acid (27.8%)	1.8	51	51	61	62	60	68	63	56	c	c	c	c
Bakelite XC-11749	None	3.9	—	—	—	—	—	—	—	—	—	—	—	—
	45% XK-11753	3.1	25	37	41	31	23	36	48	25	48	19	55	c
Bakelite XC-3931	None	4.5	—	—	—	—	—	—	—	—	—	—	—	—
	3% XK-2997	2.7	27	35	53	8	31	59	46	31	c	18	c	c
Durez 12041	None	5.0	—	—	—	—	—	—	—	—	—	—	—	—
	10% 7422	1.8	21	28	43	46	30	38	41	50	c	c	c	c

a. Decrease in strength for the unaged, oven-aged, oven-fog-aged, and roof-aged panels, respectively, is calculated on the basis of the strength of the unaged, oven-aged, oven-fog-aged, and roof-aged panels, respectively, made without catalyst.

b. Panels delaminated during exposure on roof.

c. Panels containing catalyst or reference uncatalyzed panels failed in tension rather than shear.

TABLE IX.- EFFECT OF CATALYST ON FLEXURAL STRENGTH OF BIRCH PLYWOOD BONDED WITH A RESORCINOL-FORMALDEHYDE RESIN, PENACOLITE G-1131[a]

Catalyst Added to Resin	Milliequivalents of Catalyst per 100 g of Resin	Density of Panel (g/cm³)	Resin Content of Panel (%)	pH: Resin Solution	pH: Resin Film	pH: Unaged Panel	pH: Oven-Fog-Aged Panel	pH: Roof-Aged Panel	Unaged Panel Flexural Strength Average (lb/in²)	Unaged Panel Flexural Strength Range (lb/in²)	Unaged Panel No. of Specimens	Oven-Fog-Aged Panel Flexural Strength Average (lb/in²)	Oven-Fog-Aged Panel Flexural Strength Range (lb/in²)	Oven-Fog-Aged Panel No. of Specimens	Roof-Aged Panels Flexural Strength Average (lb/in²)	Roof-Aged Panels Flexural Strength Range (lb/in²)	Roof-Aged Panels No. of Specimens	Change in Strength Due to Catalyst[b]: Unaged Panel (%)	Change in Strength Due to Catalyst[b]: Oven-Fog-Aged Panel (%)	Change in Strength Due to Catalyst[b]: Roof-Aged Panel (%)	Change in Strength Due to Aging[c]: Oven-Fog-Aged Panel (%)	Change in Strength Due to Aging[c]: Roof-Aged Panel (%)
None	—	0.93	27.1	7.3	6.5	6.1	5.5	3.7	19,100	17,600-20,600	36	19,300	17,900-20,500	36	11,100	10,200-12,000	36	—	—	—	+1.0	-41.9
Hydrochloric acid	19	0.90	22.4	4.1	4.1	4.4	3.9	3.4	18,900	16,900-20,600	36	16,800	15,600-17,700	36	10,300	9,400-11,800	36	-1.0	-13.0	-7.2	-11.1	-45.5
	24	0.91	24.0	1.5	2.5	4.1	3.8	3.5	19,300	17,200-20,400	36	17,400	15,000-18,800	36	10,300	9,000-11,500	36	+1.0	-9.8	-7.2	-9.8	-46.6
	32	0.89	22.4	0.5	1.8	3.7	3.4	3.4	18,700	17,300-19,700	36	16,800	15,100-18,700	36	9,900	8,700-11,200	36	-2.1	-13.0	-10.2	-10.2	-47.1
	64	0.91	23.5	0.6	1.3	3.0	3.2	3.2	17,700	15,000-20,500	36	13,800	10,100-16,200	36	8,200	4,100-11,000	60	-7.3	-28.5	-26.6	-22.0	-51.7
Nitric acid	19	0.88	21.9	3.3	4.4	4.6	4.3	3.6	19,400	17,500-21,200	36	18,200	16,400-19,900	36	10,200	8,900-12,200	36	+1.6	-5.7	-7.2	-6.2	-46.9
	24	0.88	22.3	1.1	2.1	4.5	4.0	3.4	18,800	16,800-20,400	36	17,600	16,300-18,900	36	9,700	8,400-10,600	36	-1.6	-8.8	-12.6	-6.4	-48.4
	32	0.90	24.1	0.6	1.7	4.1	3.8	3.5	18,700	17,300-21,000	36	17,100	15,100-18,200	36	10,000	9,100-11,100	36	-2.1	-11.4	-9.9	-8.6	-46.5
	64	0.92	24.6	0.3	1.5	3.9	3.6	3.4	18,100	12,500-20,000	36	15,000	13,700-17,200	36	8,600	6,500- 9,700	36	-5.2	-22.3	-22.5	-17.1	-52.5
Sulfuric acid	19	0.91	24.6	4.8	4.3	4.5	4.1	3.1	19,100	17,500-21,200	36	18,200	16,300-19,700	36	10,000	8,600-11,100	36	0.0	-5.7	-9.9	-4.7	-47.6
	24	0.88	21.7	2.4	3.1	4.2	4.1	3.2	19,400	17,100-22,000	36	18,700	16,500-20,000	36	10,200	9,100-11,800	36	+1.6	-3.1	-8.1	-2.6	-47.4
	43	0.90	23.7	0.3	1.7	3.3	3.1	2.8	18,400	16,100-20,400	36	16,800	14,200-18,500	36	8,300	7,000- 9,400	36	-3.7	-13.0	-25.2	-8.7	-54.9
	72	0.90	22.5	0.4	1.5	2.4	2.5	3.4	18,000	14,200-20,400	36	14,100	11,800-15,900	36	8,500	6,800-10,400	26	-5.8	-26.9	-27.4	-21.7	-52.8
Phosphoric acid	19	0.89	23.3	4.8	4.2	4.7	4.2	3.4	18,800	17,000-20,800	36	18,500	17,100-20,400	36	10,400	9,100-11,700	36	-1.6	-4.1	-6.3	-1.6	-44.7
	24	0.88	22.7	2.9	3.0	4.5	4.1	3.4	18,300	16,900-19,800	36	17,900	15,300-19,400	36	10,000	8,100-11,200	36	-4.2	-7.2	-9.7	-2.2	-45.4
	51	0.90	24.7	1.7	2.0	3.6	2.9	3.2	18,100	16,300-19,300	36	16,300	15,500-17,900	36	9,700	7,000-11,600	36	-5.2	-15.5	-12.6	-9.9	-46.4
	101	0.96	24.7	1.1	1.9	2.4	2.5	3.6	17,800	13,800-20,400	36	13,600	12,000-15,600	36	8,700	7,900- 9,600	36	-6.8	-29.5	-22.4	-28.6	-51.1
Hypophosphorous acid	20	0.87	24.4	3.8	4.0	4.5	4.3	3.5	19,500	16,000-21,500	36	18,800	17,100-22,000	36	10,900	9,400-12,300	36	+2.1	-2.6	-1.8	-3.6	-44.1
	27	0.88	24.0	2.4	2.7	4.2	4.1	3.4	19,100	17,900-20,100	36	18,300	16,800-19,500	36	10,600	9,100-12,400	36	0.0	-5.2	-4.5	-4.2	-44.5
	51	0.89	24.5	1.7	1.8	3.8	3.5	3.3	19,100	17,600-20,500	36	17,600	15,800-19,000	36	10,700	8,300-12,300	72	0.0	-8.8	-4.1	-7.8	-45.6
	100	0.91	24.1	1.4	1.6	2.6	2.4	2.5	18,800	17,500-20,100	36	15,800	13,900-18,900	36	9,000	6,400-12,100	35	-1.6	-18.1	-14.9	-16.0	-52.1
Benzenesulfonic acid	19	0.86	21.3	4.4	4.2	4.5	4.3	3.1	19,400	18,000-20,800	36	18,200	17,100-19,900	36	10,200	7,800-12,400	36	+1.6	-5.7	-8.1	-6.2	-47.4
	24	0.87	22.3	1.3	2.7	4.2	4.1	3.2	20,100	17,900-21,300	36	18,800	17,000-20,400	36	10,600	9,500-12,400	36	+5.2	-2.6	-4.5	-6.5	-47.3
	32	0.89	25.6	0.4	1.9	3.5	3.7	3.1	19,600	17,400-20,800	36	17,800	14,800-19,900	36	9,500	8,200-11,300	36	+2.6	-7.8	-14.4	-9.2	-51.5
	64	0.90	21.6	0.5	1.4	3.1	3.2	3.2	18,900	17,200-20,700	36	15,600	13,200-17,700	36	9,400	7,200-12,100	36	-1.0	-19.2	-15.3	-17.5	-50.3
Trichloroacetic acid	21	0.87	20.5	2.8	4.0	5.7	5.0	3.8	18,700	16,900-20,500	36	18,200	16,300-20,200	36	10,700	9,700-11,600	36	-2.1	-5.7	-3.6	-2.7	-42.8
	27	0.86	20.4	1.6	2.7	5.5	5.0	3.7	19,200	17,600-20,800	36	18,600	17,300-20,800	36	10,800	10,200-11,600	36	+0.5	-3.6	-2.7	-3.1	-43.8
	43	0.85	21.0	1.2	1.6	5.3	5.1	3.7	18,500	15,800-20,000	36	16,900	14,900-18,800	36	10,300	9,000-11,000	36	-3.1	-12.4	-7.2	-8.6	-44.3
	85	0.89	21.5	1.0	1.4	5.0	4.7	4.1	19,300	16,700-21,100	36	16,500	13,100-18,900	36	10,300	9,300-11,400	36	+1.0	-14.5	-7.2	-14.5	-46.6
Nitranilic acid	21	0.86	21.3	5.5	4.6	5.0	4.5	3.4	18,800	13,800-21,100	36	18,400	15,400-21,400	36	10,100	9,000-11,600	36	-1.6	-4.7	-9.0	-2.1	-46.3
	32	0.86	21.8	1.1	3.0	4.4	4.0	3.4	18,600	14,600-20,100	36	17,900	15,400-20,200	36	10,000	8,600-12,000	36	-2.6	-7.2	-10.9	-3.8	-46.2
	43	0.87	22.2	0.7	2.7	4.1	3.9	3.3	18,200	16,400-20,300	36	16,700	15,200-17,700	36	9,300	7,700-11,200	34	-4.7	-13.5	-16.2	-8.2	-48.9
Sodium hydroxide	440	1.08	35.3	10.5	11.5	9.2	8.5	—	19,200	16,900-21,500	30	16,000	14,300-18,000	30	—	—	—	+0.5	-17.1	—	-16.7	—

a. All panels prepared by pressing at 150°F for 24 hours, using metal bars to control thickness.

b. Change in strength for the unaged and oven-fog-aged panels, respectively, is calculated on the basis of the strength of the unaged and oven-fog-aged panels, respectively, made without catalyst.

c. Change in strength calculated on the basis of the strength of the unaged panel.

TABLE X.- EFFECT OF ALKALI AND ACIDS ON PHENOLIC RESIN-BONDED PLYWOOD[a]

Catalyst Added to Resin	Milliequivalents of Catalyst per 100 g of Resin	Density of Panel (g/cm³)	pH: Resin Solution	pH: Resin Film	pH: Unaged Panel	pH: Oven-Fog-Aged Panel	pH: Roof-Aged Panel	Unaged Panels: Average (lb/in²)	Unaged Panels: Range (lb/in²)	Unaged Panels: No. of Specimens	Oven-Fog-Aged Panels: Average (lb/in²)	Oven-Fog-Aged Panels: Range (lb/in²)	Oven-Fog-Aged Panels: No. of Specimens	Roof-Aged Panels: Average (lb/in²)	Roof-Aged Panels: Range (lb/in²)	Roof-Aged Panels: No. of Specimens	Change in Strength Due to Catalyst[b]: Unaged Panel (%)	Change in Strength Due to Catalyst[b]: Oven-Fog-Aged Panel (%)	Change in Strength Due to Catalyst[b]: Roof-Aged Panel (%)	Change in Strength Due to Aging[c]: Oven-Fog-Aged Panel (%)	Change in Strength Due to Aging[c]: Roof-Aged Panel (%)
CASCOPHEN LT-67 AND H-15																					
None	—	0.98	6.5	8.7	6.7	6.4	5.2	22,100	15,700-24,000	36	24,000	21,400-26,400	36	13,000	11,700-15,000	36	—	—	—	+8.6	-41.2
Sodium hydroxide	460	1.03	12.1	12.2	7.6	6.2	5.7	22,100	19,500-24,000	36	18,800	17,300-20,500	36	13,900	11,900-15,200	36	0.0	-21.7	+6.9	-14.9	-37.1
	230	0.95	11.3	11.0	8.3	7.8	6.1	21,800	16,700-23,800	36	19,700	17,800-21,800	36	14,300	12,400-16,900	36	-1.4	-17.9	+10.0	-9.6	-34.4
	105	0.98	10.6	10.4	7.6	7.7	5.7	21,800	20,100-23,800	36	20,400	17,900-21,800	36	13,500	12,000-14,700	36	-1.4	-15.0	+3.8	-6.4	-38.1
	33	0.97	9.3	10.0	7.2	6.9	5.5	21,300	18,900-23,500	36	20,500	19,000-22,000	36	12,900	11,800-15,500	36	-3.6	-14.6	-0.8	-3.8	-25.4
Trichloroacetic acid	41	0.94	5.5	5.3	6.5	6.6	4.5	21,000	18,700-23,400	36	22,200	18,300-24,900	36	12,200	10,900-13,900	36	-5.0	-7.5	-6.2	+5.7	-41.9
	49	0.92	2.1	4.4	6.5	6.4	5.0	20,200	16,700-23,300	36	20,900	18,700-23,700	36	11,600	9,400-14,400	36	-8.6	-12.9	-10.8	+3.5	-42.6
	94	0.89	1.5	1.7	4.7	6.3	4.6	19,500	16,800-22,400	36	20,500	18,400-22,000	36	12,700	11,100-14,000	36	-11.8	-14.6	-2.3	+5.1	-34.9
Benzenesulfonic acid	39	0.92	6.2	5.6	4.7	4.5		21,200	19,000-24,900	48	21,200	18,700-23,600	48	—	—	—	-4.1	-11.7	—	0.0	—
	45	0.90	3.1	4.1	5.4	4.2		20,400	18,300-23,500	48	20,700	18,500-22,800	48	—	—	—	-7.7	-13.8	—	+1.5	—
	61	0.87	0.8	2.2	3.4	3.5		17,900	15,300-21,400	48	17,400	15,600-19,400	48	—	—	—	-19.0	-27.5	—	-2.8	—
Hypophosphorous acid	43	1.04	6.4	5.6	4.6	4.0		24,200	20,800-26,100	48	22,700	21,300-24,800	48	—	—	—	+9.5	-5.4	—	-6.2	—
	98	1.06	2.7	2.6	3.9	3.6		25,000	22,200-28,000	48	23,700	21,300-25,900	48	—	—	—	+13.1	-1.2	—	-5.2	—
	116	0.94	1.9	1.6	2.2	2.1		19,700	17,700-22,200	48	13,600	11,600-14,900	48	—	—	—	-10.9	-43.3	—	-31.0	—
DUREZ 12041																					
None	—	1.02	7.1	8.1	4.9	4.8		26,800	21,300-29,600	48	24,700	20,900-27,000	48	—	—	—	—	—	—	-7.8	—
Hypophosphorous acid	43	0.93	2.1	1.9	3.4	3.4		21,500	18,000-24,500	48	19,700	15,900-23,200	48	—	—	—	-19.8	-20.2	—	-8.4	—
	98	1.02	2.3	1.8	3.1	2.5		23,500	20,000-26,600	48	22,200	19,000-24,400	48	—	—	—	-12.3	-10.1	—	-5.5	—
	116	0.94	1.2	1.3	2.2	2.2		19,400	16,400-21,300	48	15,800	13,600-19,100	48	—	—	—	-27.6	-36.0	—	-18.6	—

a. All panels prepared by pressing at 180°F for 24 hours, using metal bars to control thickness.

b. Change in strength for the unaged, oven-fog-aged, and roof-aged panels, respectively, is calculated on the basis of the strength of the unaged, oven-fog-aged, and roof-aged panels, respectively, made without catalyst.

c. Change in strength calculated on the basis of the strength of the unaged panel.

TABLE XI.- THE EFFECT OF VARYING RESIN AND CATALYST ON THE FLEXURAL STRENGTH OF PHENOLIC RESIN-BONDED BIRCH PLYWOOD

Commercial Designation of Resin	Catalyst Added to Resin	Classification	Conditions of Cure: Temperature (°F)	Conditions of Cure: Time (hr:min)	Density (g/cm³)	Resin Content (%)	pH: Film	pH: Unaged Panel	pH: Oven-Fog-Aged Panel	pH: Roof-Aged Panel	Unaged Panel Flexural Strength: Average (lb/in²)	Unaged Panel Flexural Strength: Range (lb/in²)	Unaged Panel: No. of Specimens	Oven-Fog-Aged Panel Flexural Strength: Average (lb/in²)	Oven-Fog-Aged Panel Flexural Strength: Range (lb/in²)	Oven-Fog-Aged Panel: No. of Specimens	Roof-Aged Panel Flexural Strength: Average (lb/in²)	Roof-Aged Panel Flexural Strength: Range (lb/in²)	Roof-Aged Panel: No. of Specimens	Change in Strength Due to Catalyst[a]: Unaged Panel (%)	Change in Strength Due to Catalyst[a]: Oven-Fog-Aged Panel (%)	Change in Strength Due to Catalyst[a]: Roof-Aged Panel (%)	Change in Strength Due to Aging[b]: Oven-Fog-Aged Panel (%)	Change in Strength Due to Aging[b]: Roof-Aged Panel (%)
Bakelite XC-11749	None	N	300	0:45	0.94	26	5.9	4.8	4.4	3.7	24,600	22,100-26,800	15	21,900	18,300-24,100	15	14,200	11,500-16,000	15	—	—	—	-11	-42
	45% XK-11753	R	Room	20:00	0.86	31	1.5	5.1	5.3	3.3	16,400	15,400-19,700	15	12,900	8,700-15,700	15	9,800	6,000-11,400	12	-33	-41	-31	-30	-47
	3.3% XK-2997	R	150	20:00	0.94	29	1.8	5.0	3.3	3.0	16,800	15,600-23,000	16	13,500	11,600-16,600	16	9,000	6,000-11,000	16	-24	-38	-37	-24	-58
	10% Durez 7422	R	150	20:00	0.95	31	1.4	1.9	2.2	2.8	22,100	19,900-25,600	16	11,800	9,800-13,400	16	8,200	6,500-9,100	16	-10	-46	-42	-47	-63
Bakelite XC-3931	None	N	300	0:30	0.97	35	5.5	4.5	4.5	3.5	23,600	16,100-30,000	15	24,800	23,300-26,300	15	10,700	9,100-12,800	15	—	—	—	+5	-55
	45% XK-11753	R	150	20:00	0.94	35	1.3	1.5	1.7	2.9	21,800	19,400-24,400	15	17,700	14,300-20,400	15	6,000	2,100-8,800	16	-8	-29	-25	-19	-65
	7.2% XK-2447	R	(Room / 150	20:00 / 2:00)	0.90	31	1.5	2.7	3.0	3.3	17,300	15,200-19,900	12	11,600	3,800-13,800	12	9,600	4,900-11,500	12	-27	-53	-8	-33	-45
	10% Durez 7422	R	Room	20:00	1.02	43	1.8	1.6	2.0	3.0	18,100	16,700-19,200	16	12,800	11,000-14,000	16	7,800	6,900-9,200	16	-23	-48	-27	-29	-57
Durez 12041[c]	None	N	300	0:30	0.97	33	6.2	5.0	5.0	4.7	24,700	22,400-26,700	15	23,800	21,300-27,300	15	17,800	15,300-21,000	15	—	—	—	-4	-28
	3.3% XK-2997	R	Room	20:00	1.02	36	1.3	4.6	4.6	4.3	21,800	19,900-24,800	15	24,300	18,800-27,700	15	11,000	7,900-14,500	15	-12	+2	-38	+11	-50
	10% Durez 7422	M	150	24:00	0.97	36	1.4	1.4	1.9	2.6	19,400	17,300-20,600	12	13,500	10,100-15,300	12	9,600	8,400-10,900	12	-21	-43	-46	-30	-51
Bakelite XC-11749	None	N	300	0:45	0.94	26	5.9	4.8	4.4	3.7	24,600	22,100-26,800	15	21,900	18,300-24,100	15	14,200	11,500-16,000	15	—	—	—	-11	-42
	3% XK-11753	M	150	20:00	0.93	27	4.2	4.7	4.5	3.2	22,600	20,900-24,800	15	20,700	17,600-22,900	15	9,400	6,700-10,800	15	-8	-5	-31	-8	-57
	20% XK-11753	M	150	3:00	0.89	27	2.3	4.0	3.9	3.3	21,700	16,700-20,300	16	17,000	16,700-20,100	16	5,400	7,100-11,400	16	-12	-22	-36	-22	-57
	30% XK-11753	M	150	3:00	0.89	27	2.7	4.0	3.8	3.4	20,400	17,300-22,800	16	17,200	15,100-19,600	16	8,700	7,300-9,700	16	-17	-21	-39	-16	-57
	45% XK-11753	M	Room	20:00	0.88	31	1.9	3.1	3.3	3.3	18,400	15,400-19,700	12	12,900	8,700-15,300	12	9,800	6,000-11,400	12	-45	-41	-31	-30	-47

a. Change in strength for the unaged, oven-fog-aged, and roof-aged panels, respectively, is calculated on the basis of the strength of the unaged, oven-fog-aged, and roof-aged panels, respectively, made without catalyst.

b. Change in strength calculated on the basis of the strength of the unaged panel.

c. This resin would not cure with catalyst XK-11753 at 150°F.

TABLE XII.-EFFECT OF CATALYSTS ON FLEXURAL STRENGTH OF BIRCH VENEERS[a]

Catalyst	Normality of Solution	pH: Original Solution	pH: Solution After Wood Immersion	pH: Ground Wood	Flexural Strength: Average (lb/in²)	Flexural Strength: Range (lb/in²)	Flexural Strength: No. of Speci-mens	Flexural Strength: Loss in Strength[b] (%)
Hydrochloric acid	1.0	0.12	0.03	1.5	9,800	8,600-12,800	10	52.2
	0.1	1.1	1.4	2.4	14,900	13,000-16,500	12	27.3
	0.01	2.0	3.1	4.0	18,100	18,800-18,900	12	11.7
	Water	5.5	5.2	5.6	18,700	17,100-20,000	12	8.8
	Untreated wood[a]			6.0	20,500	19,100-22,700	12	—
Nitric acid	1.0	0.1	0.21	1.6	12,300	10,800-13,800	12	42.0
	0.1	1.1	1.4	2.4	17,100	16,100-18,800	12	19.3
	0.01	2.0	3.4	4.2	20,400	18,900-22,700	12	3.8
	Water	5.5	4.9	5.3	20,700	18,900-22,200	12	2.4
	Untreated wood			5.8	21,200	19,100-22,900	12	—
Sulfuric acid	1.0	0.33	0.34	1.5	12,300	10,700-13,400	12	38.2
	0.1	1.3	1.4	2.4	16,400	14,700-17,700	12	17.6
	0.01	2.1	3.1	4.2	19,200	17,800-20,800	12	3.5
	Water	5.6	5.5	5.4	19,300	18,500-20,400	12	3.0
	Untreated wood			5.5	19,900	18,900-21,600	12	—
Phosphoric acid	3.0	0.8	0.88	1.8	15,000	13,900-16,700	12	25.0
	0.3	1.6	1.8	2.4	18,000	16,600-19,200	12	10.0
	0.03	2.2	3.2	4.1	18,600	15,600-20,100	12	7.0
	Water	5.5	6.0	5.4	18,500	16,800-20,800	12	9.2
	Untreated wood			5.5	20,000	17,600-23,400	12	—
Hypophosphorous acid	1.0	0.6	0.72	1.5	14,700	12,900-16,900	12	28.3
	0.1	1.3	1.6	2.2	19,300	17,400-20,400	12	5.9
	0.01	2.2	3.1	4.0	19,900	18,900-20,700	12	2.9
	Water	5.5	5.2	4.7	19,800	18,100-20,300	12	3.4
	Untreated wood			4.9	20,500	19,500-21,200	12	—
Benzenesulfonic acid	1.0	0.1	0.18	1.1	10,400	9,600-11,300	12	49.0
	0.1	1.1	1.2	2.1	16,100	13,900-17,800	12	21.1
	0.01	2.0	3.2	3.8	18,900	16,900-20,400	12	7.4
	Water	5.5	5.4	5.0	18,800	17,300-21,000	12	7.8
	Untreated wood			4.9	20,400	18,900-22,700	12	—
Trichloroacetic acid	1.1	0.1	0.56	1.2	14,000	12,400-15,100	12	27.5
	0.11	1.2	1.1	2.4	17,100	15,600-19,400	12	11.4
	0.01	2.1	2.7	4.2	17,300	15,400-19,100	12	10.4
	Water	5.9	5.0	5.2	18,200	16,500-20,200	12	5.7
	Untreated wood			5.3	19,300	17,000-21,400	12	—
Nitranilic acid	1.0	0.42	0.80	1.8	16,600	15,500-17,800	12	19.4
	0.2	1.0	1.6	2.4	18,800	18,200-19,900	12	8.7
	0.02	1.9	2.7	3.8	18,900	18,100-20,400	12	8.2
	Water	5.5	5.0	5.3	19,400	17,700-20,000	12	5.8
	Untreated wood			5.8	20,600	19,700-21,200	12	—
Sodium hydroxide	0.1	12.9	10.2	7.0	20,200	18,700-22,300	12	6.0
	0.01	12.0	6.0	6.2	20,100	17,900-22,300	12	6.5
	Water	5.8	5.0	5.4	20,100	18,800-21,700	12	6.5
	Untreated wood			5.7	21,500	20,700-22,400	12	—
Tetraethanol ammonium hydroxide	0.44	12.4	11.7	8.8	16,300	12,800-17,900	12	20.1
	0.22	12.1	8.8	7.1	19,000	17,700-21,100	12	6.9
	Water	5.6	5.0	5.1	20,100	18,200-21,300	12	1.5
	Untreated wood			5.5	20,400	18,900-22,500	12	—

a. A birch veneer of 0.1-inch thickness was cut into the required number of specimens for treatment with a single catalyst. The specimens for immersion in each concentration of the catalyst for 3 days were selected so as to be representative of the whole veneer. Two similar sets of specimens from the same veneer were tested untreated and after immersion in distilled water for 3 days, respectively.

b. The percentage loss in flexural strength is calculated on the basis of the strength of the untreated wood from the same veneer.

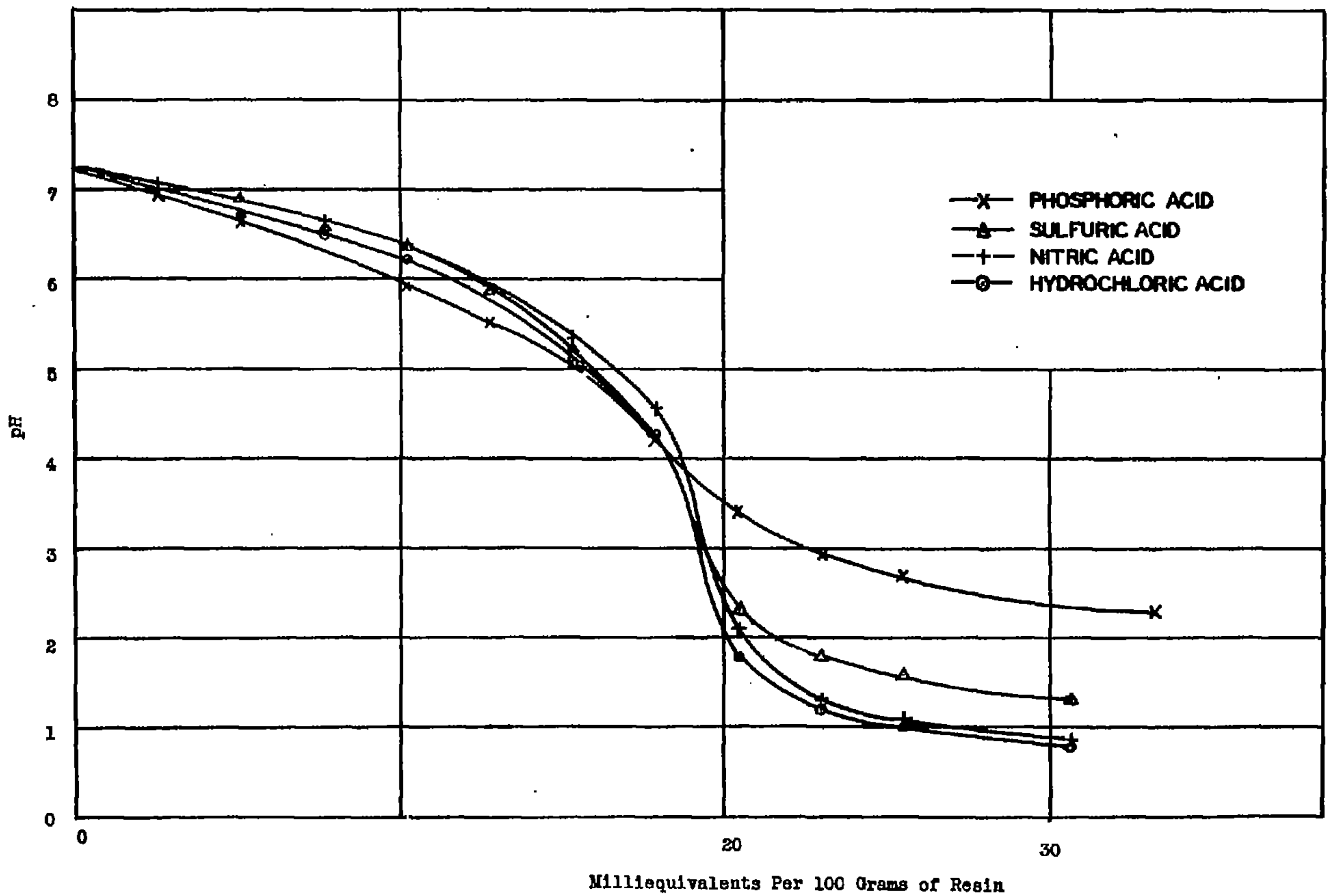

Figure 1.- Titration of Penacolite G-1131 with various acids.

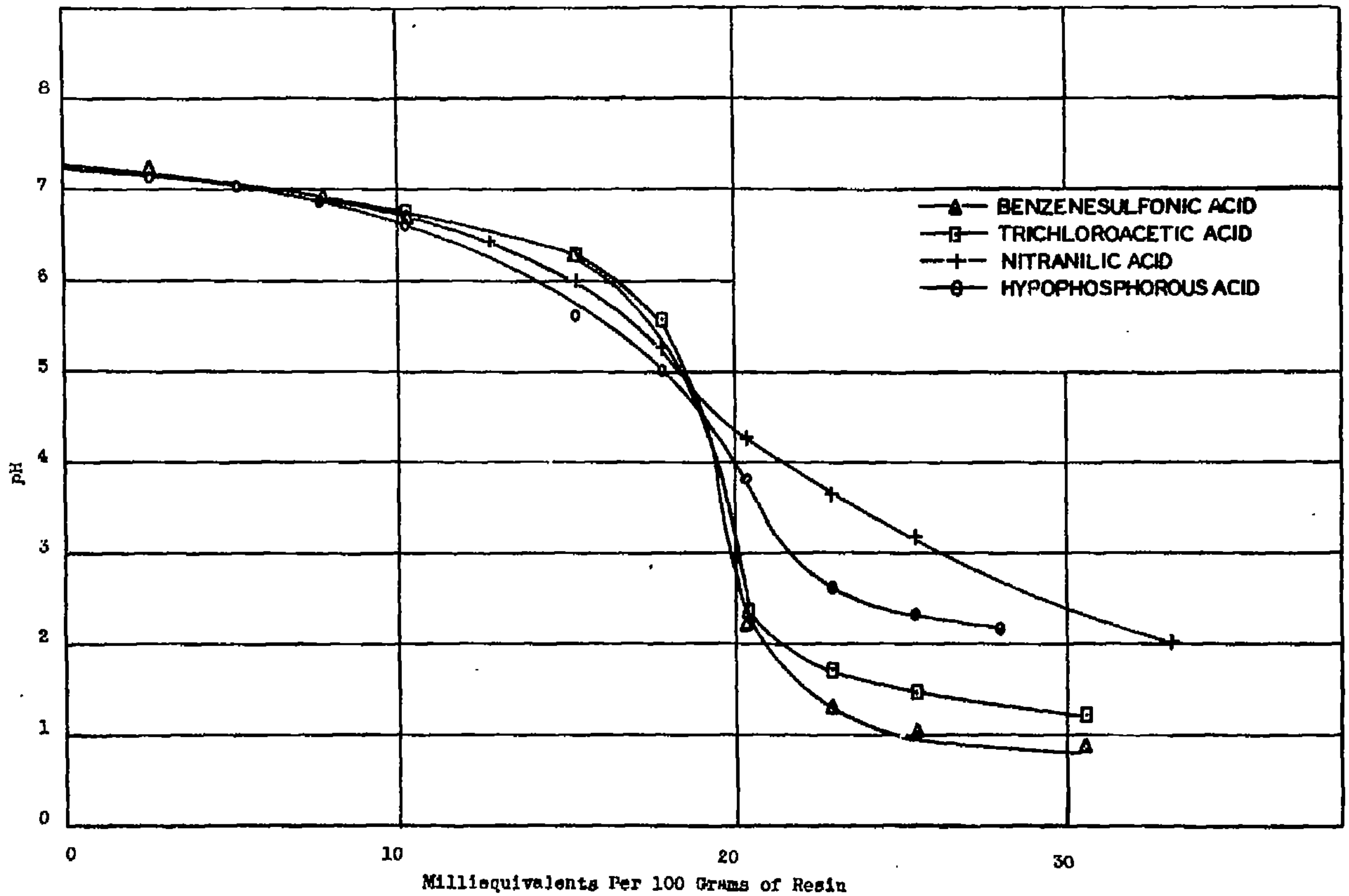

Figure 2.- Titration of Penacolite G-1131 with various acids

WC-3

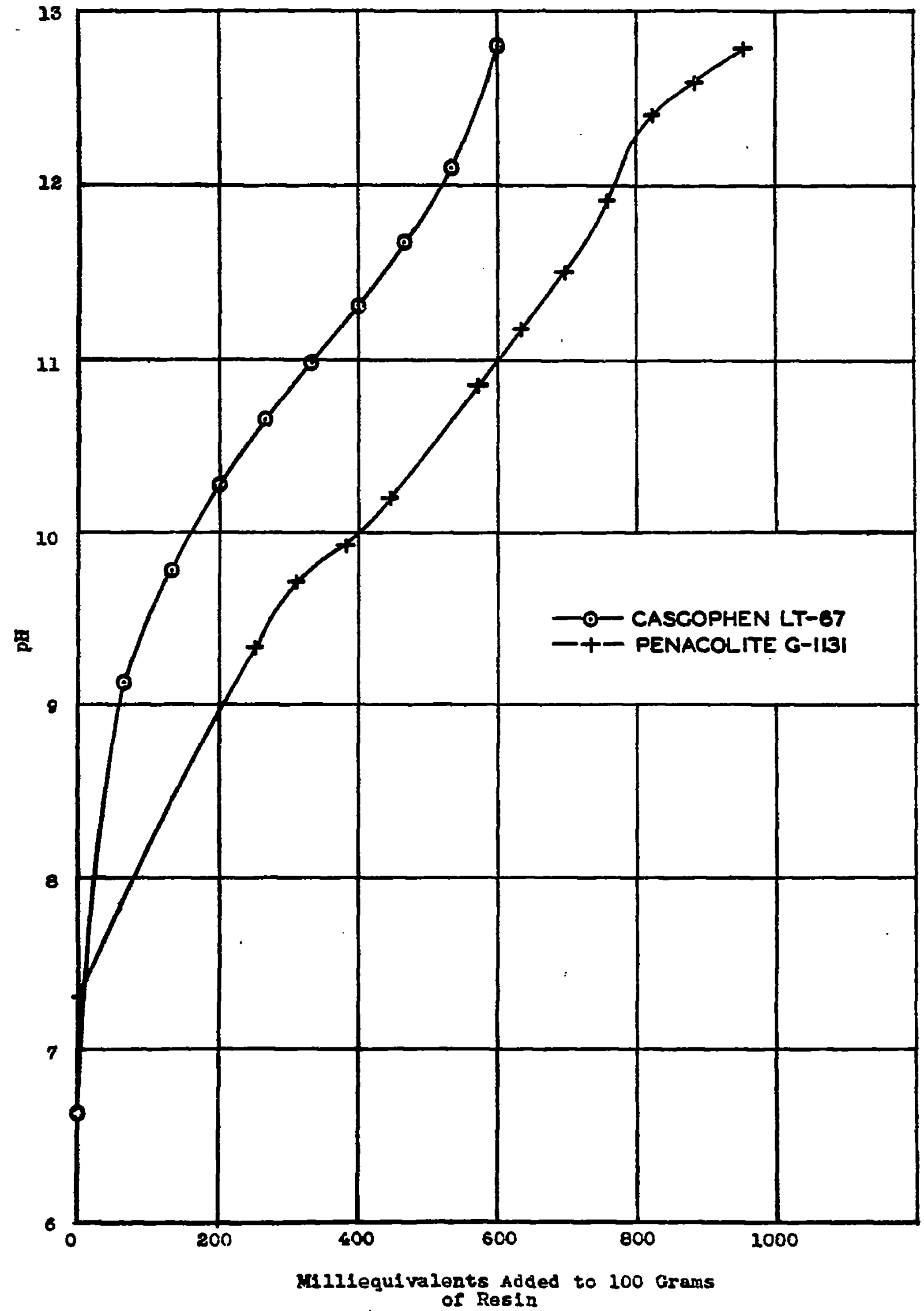

Figure 3.- Titration of phenol and resorcinol resins with sodium hydroxide.

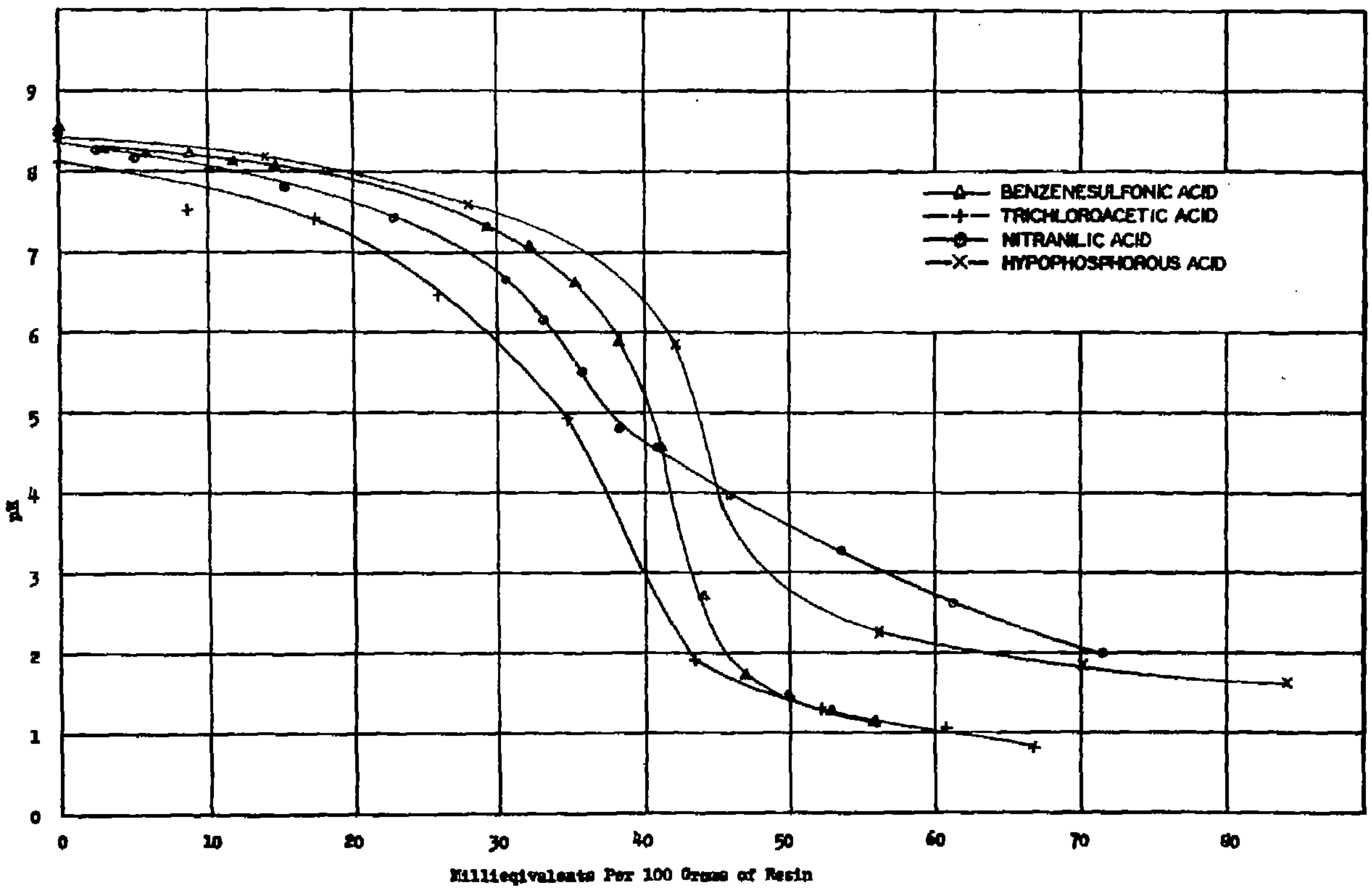

Figure 4.- Titration of Cascophen LT-67 with various acids.

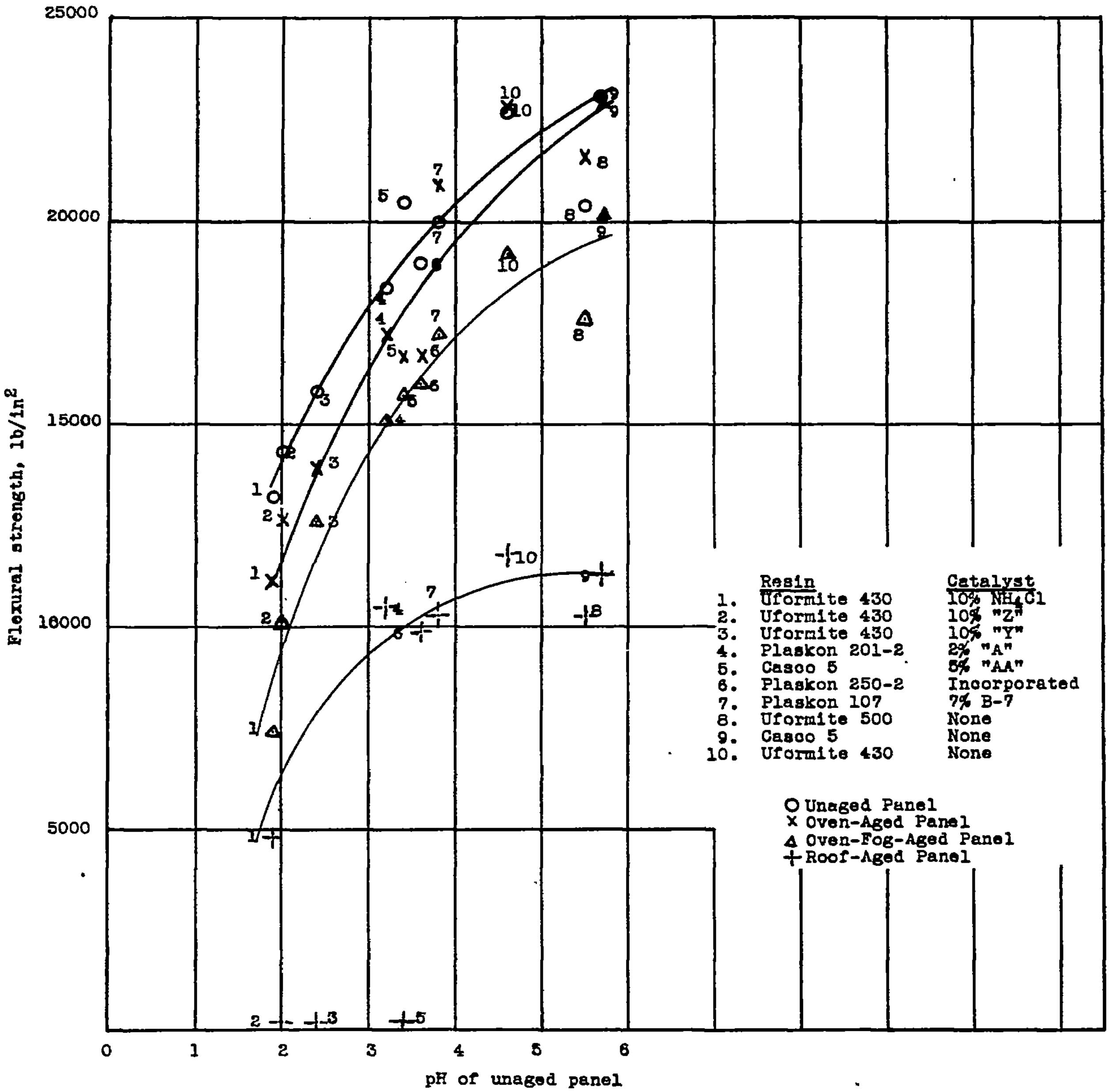

Figure 5.- Effect of pH on flexural strength of birch plywood bonded with urea-formaldehyde resins.

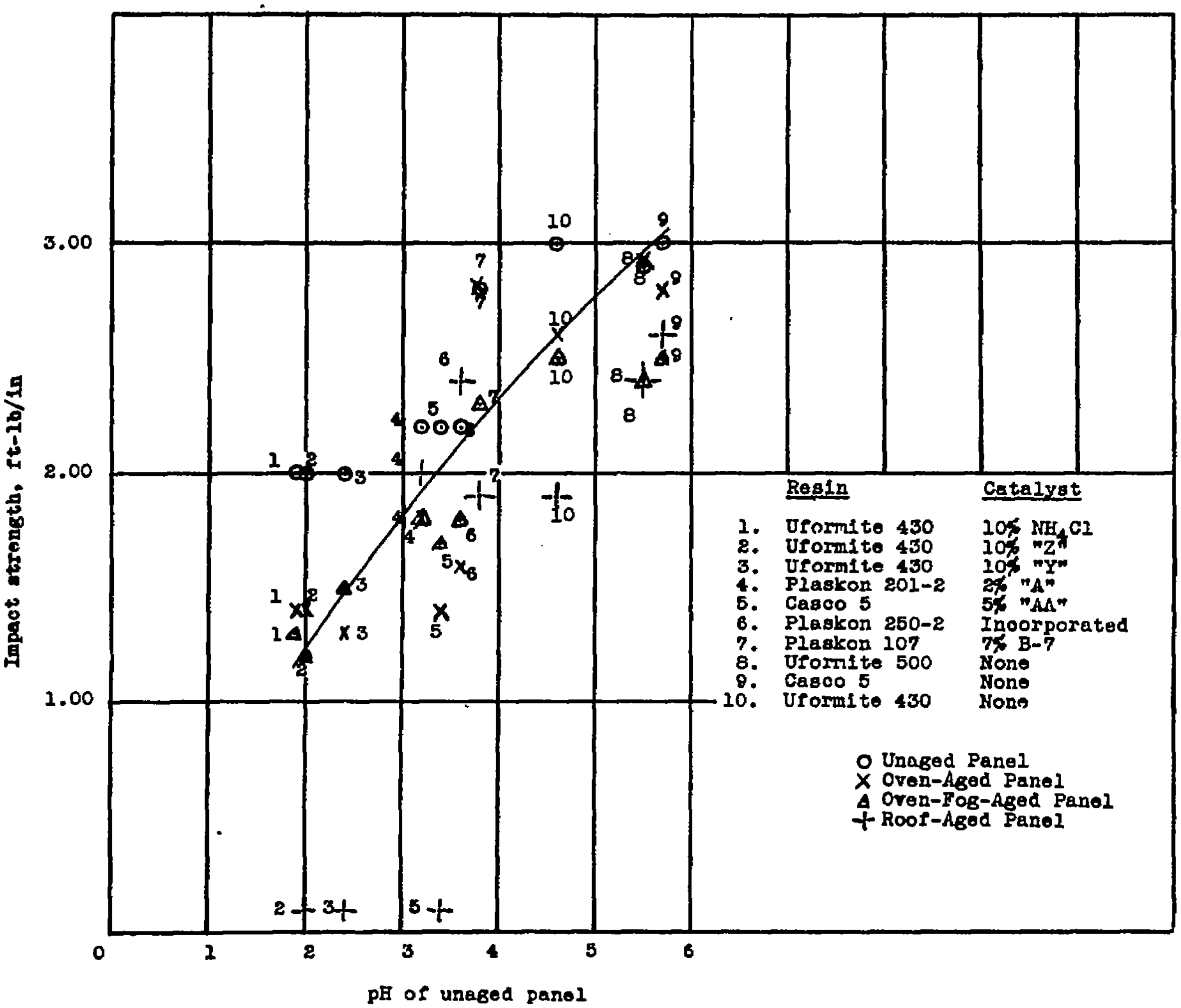

Figure 6.- Effect of pH on impact strength of birch plywood bonded with urea-formaldehyde resins.

WC-3

WC-3

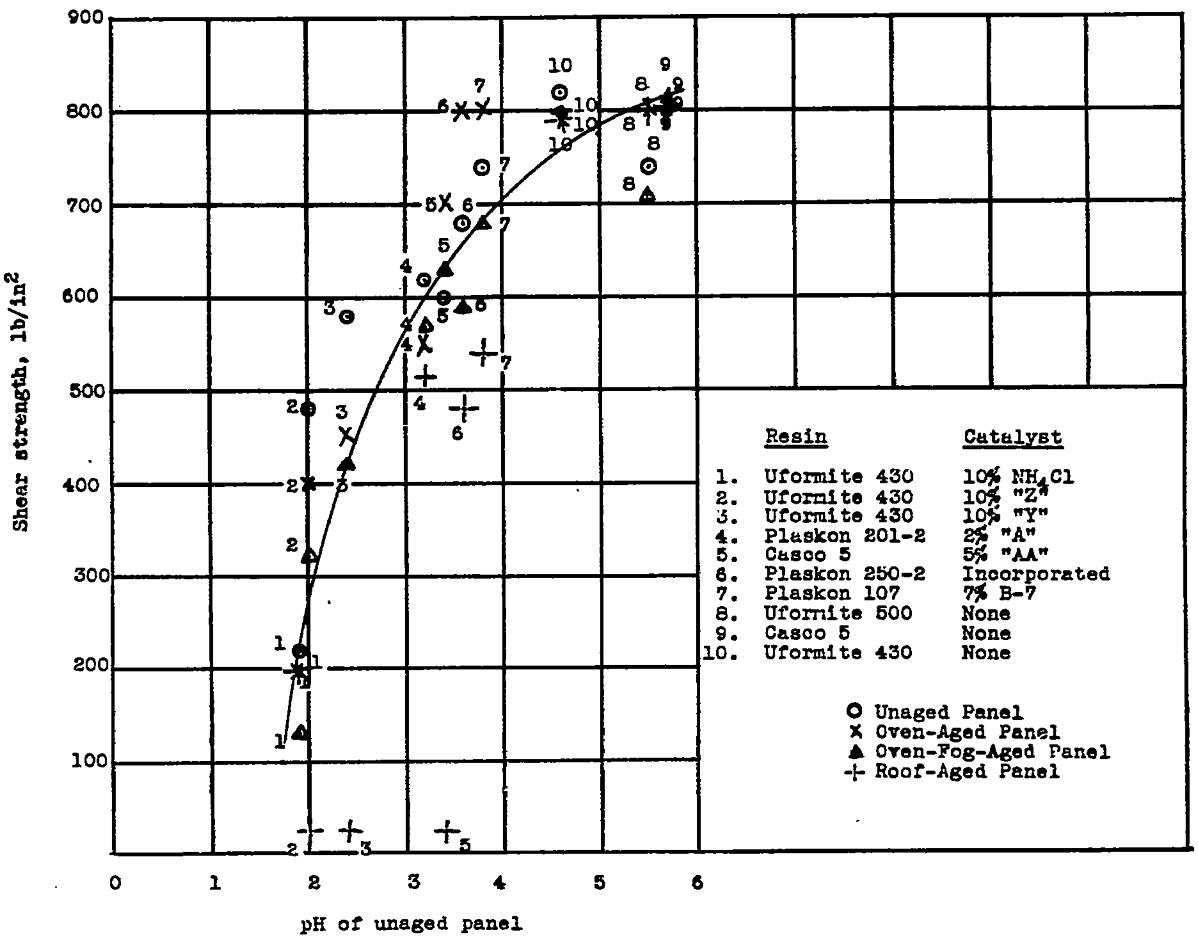

Figure 7.- Effect of pH on shear strength of birch plywood bonded with urea-formaldehyde resins.

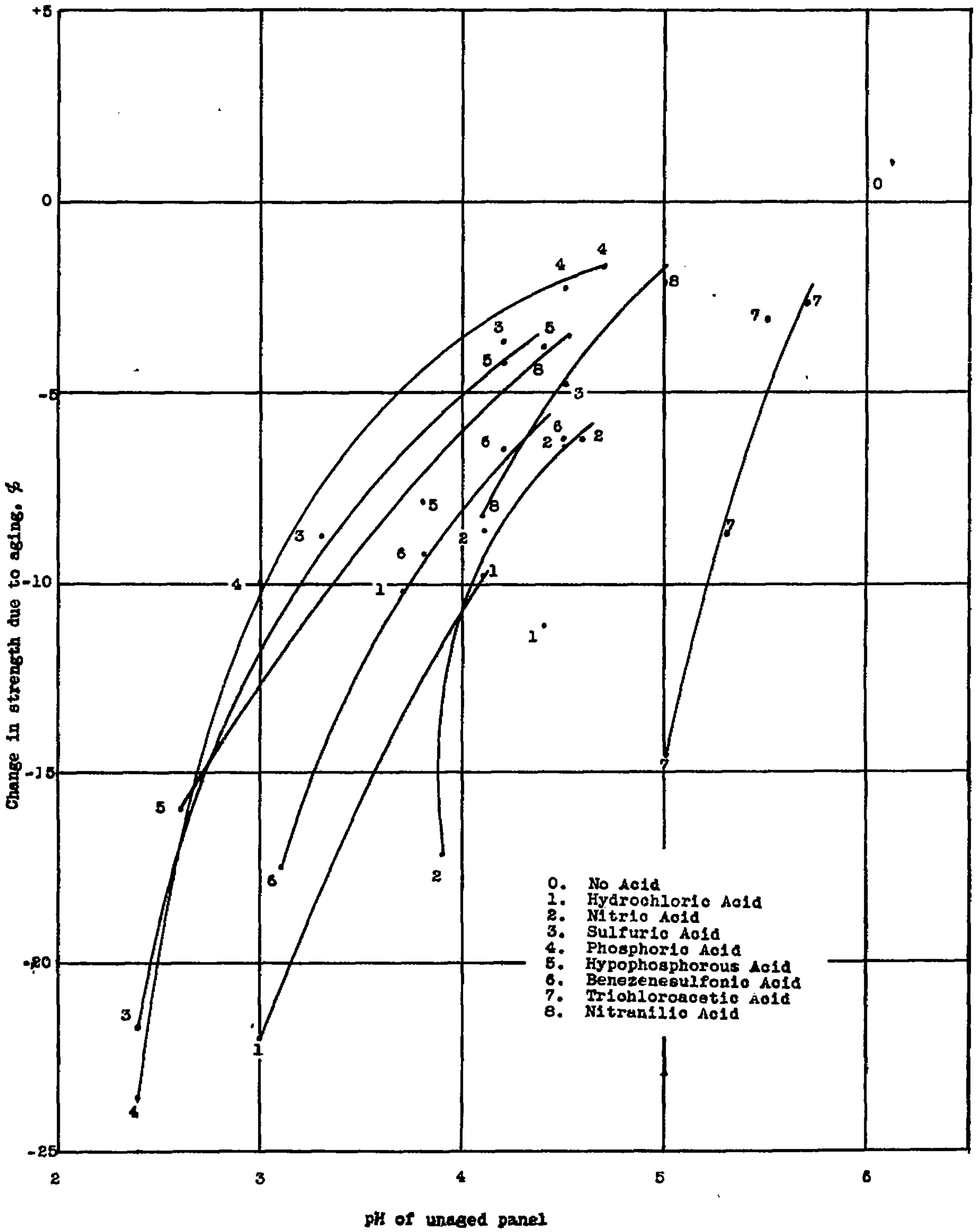

Figure 8.- Effect of oven-fog-aging on flexural strength of birch plywood bonded with Penacolite G-1131, using various acid catalysts.

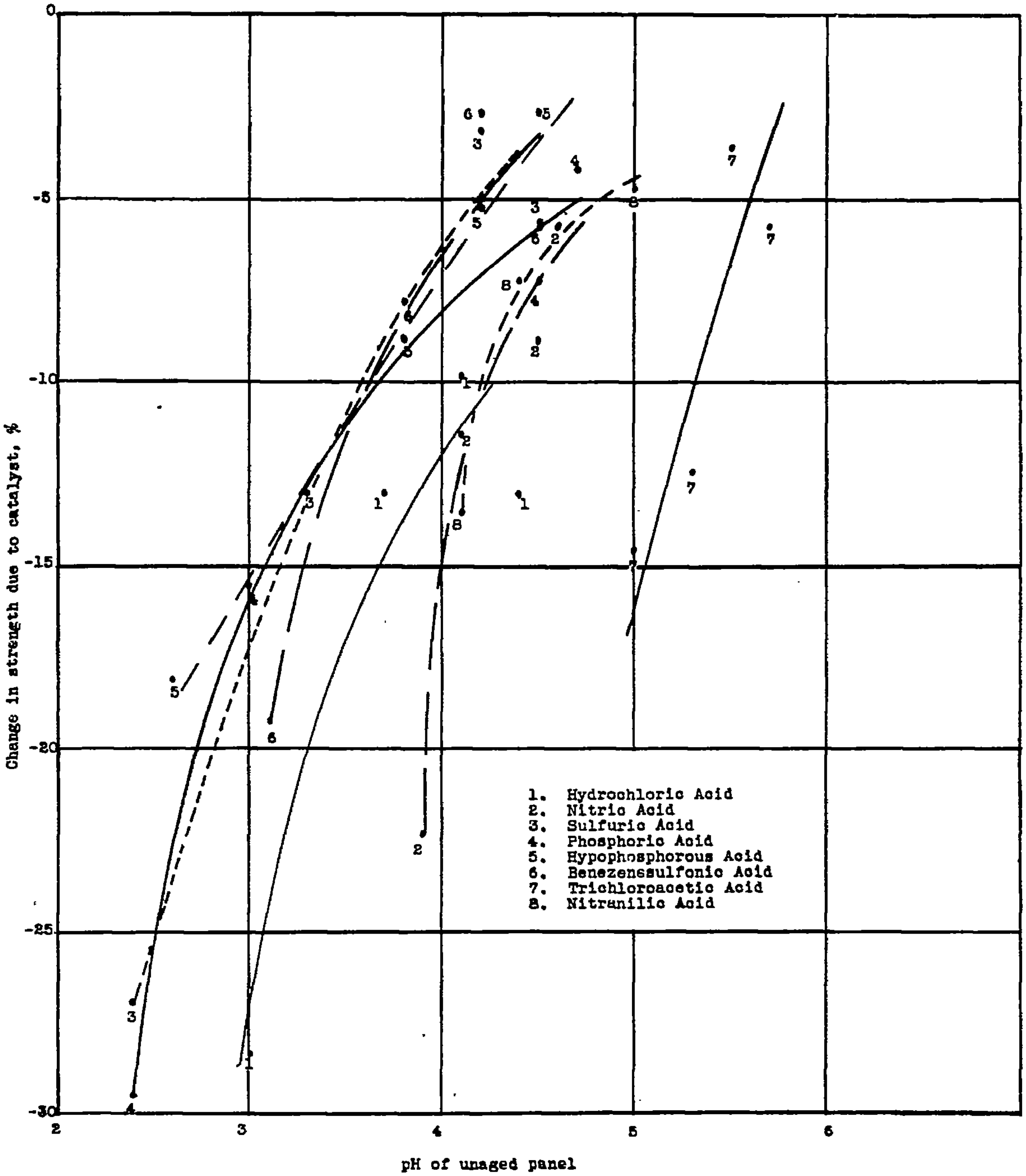

Figure 9.- Effect of various acid catalysts on flexural strength of oven-fog-aged birch plywood bonded with Penacolite G-1131.

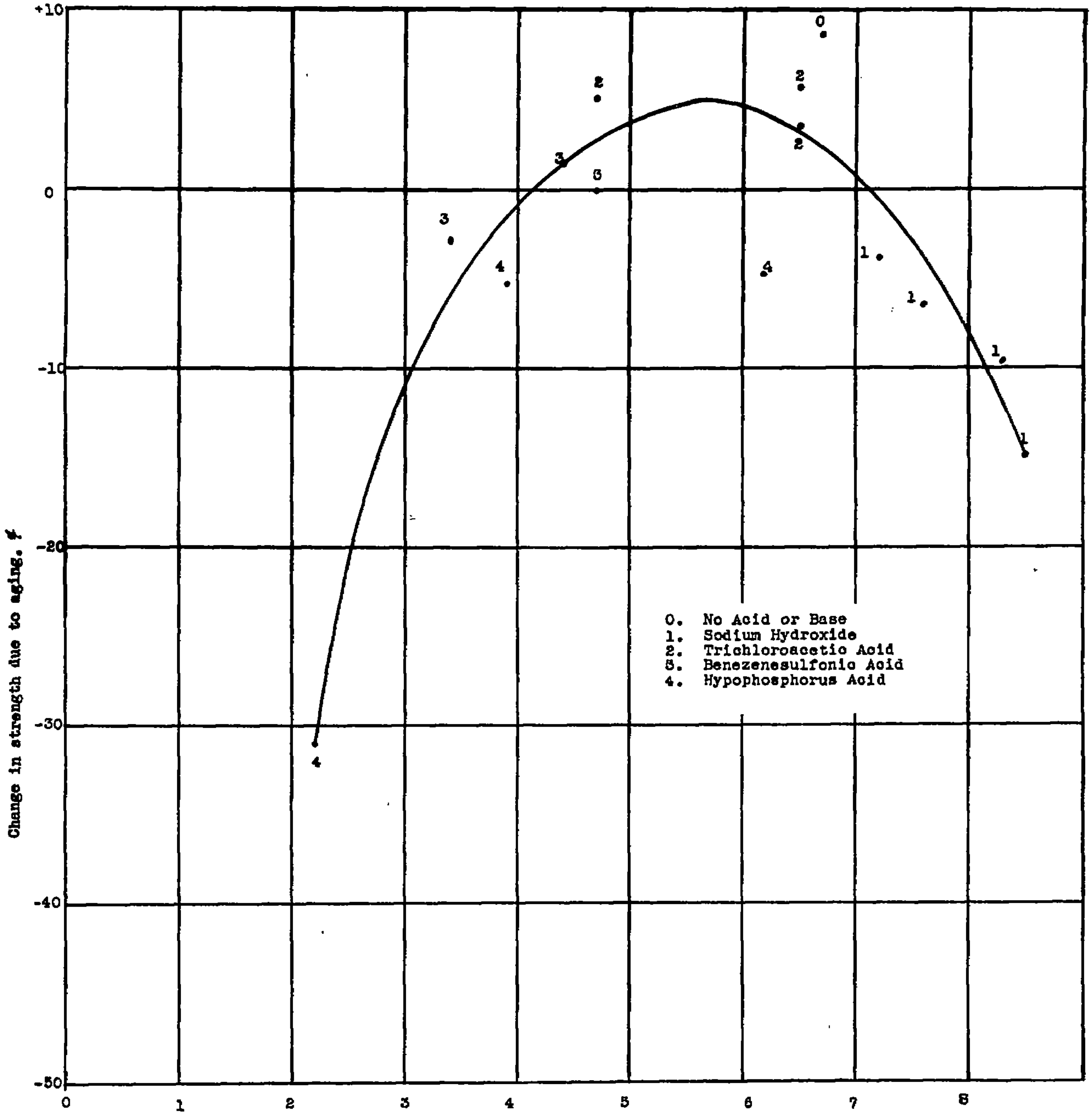

Figure 10.- Effect of oven-fog-aging on flexural strength of birch plywood bonded with Cascophen LT-67, using acidic and basic catalysts.

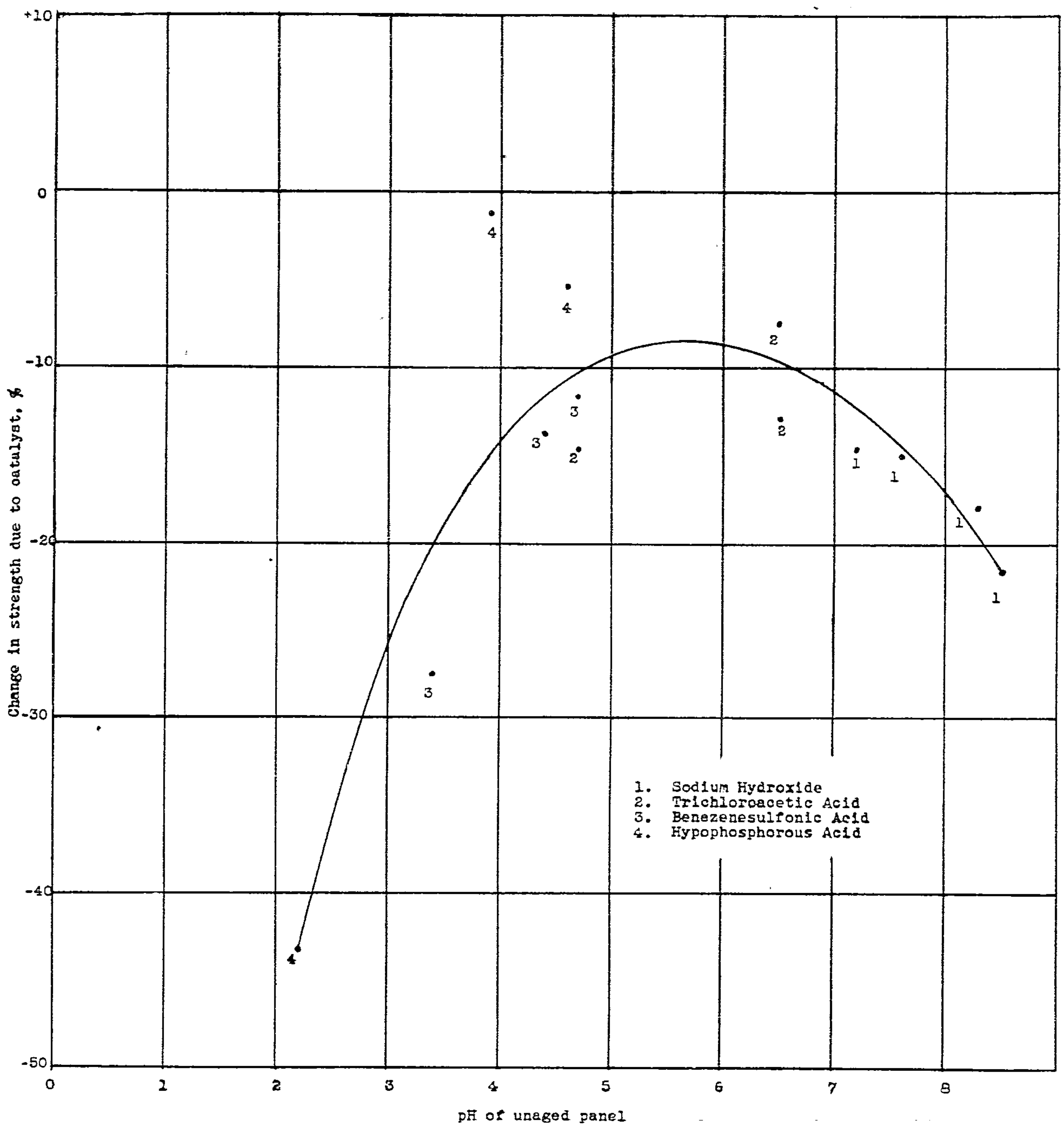

Figure 11.- Effect of various catalysts on flexural strength of oven-fog-aged birch plywood bonded with Cascophen LT-67.

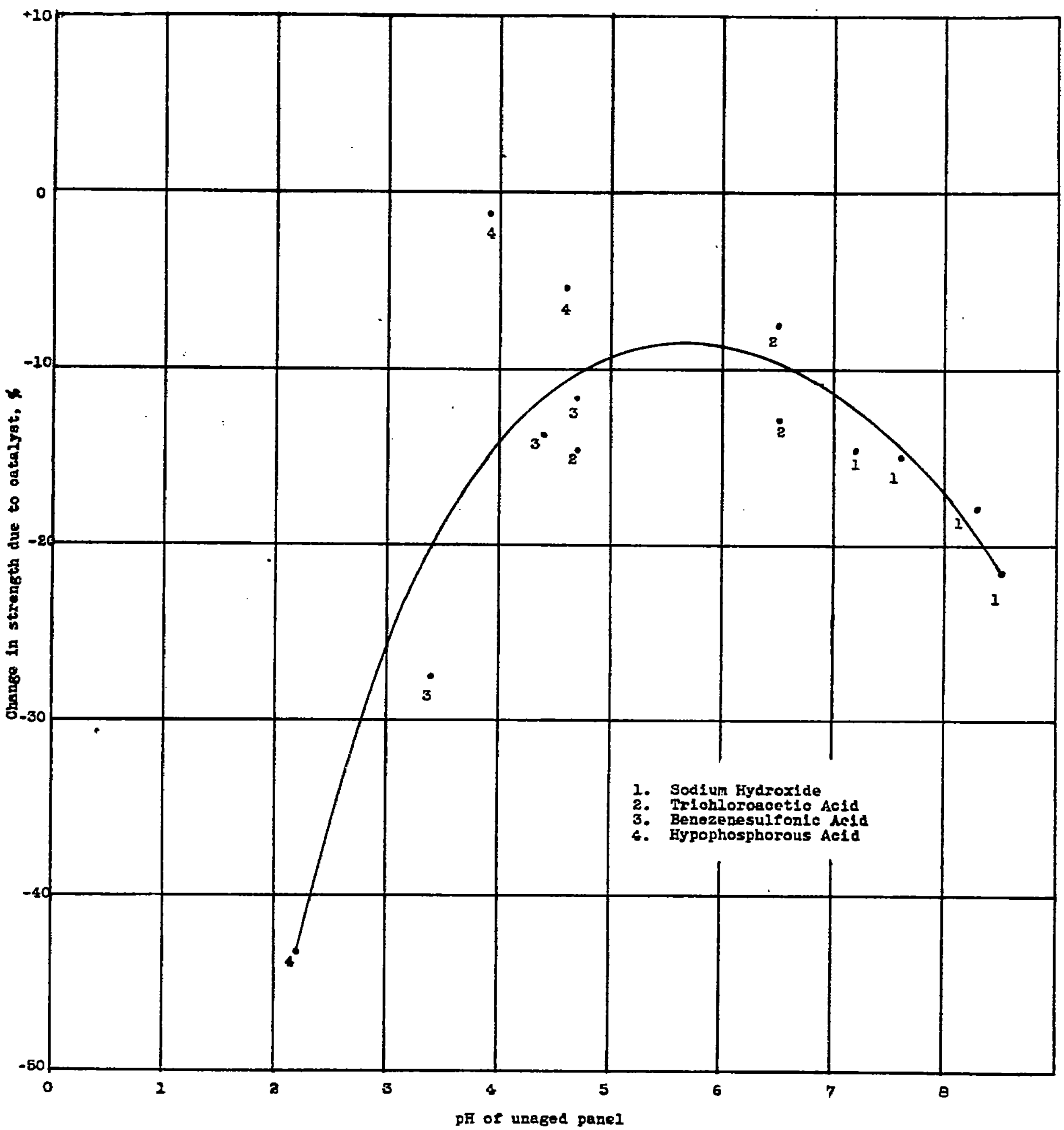

Figure 11.- Effect of various catalysts on flexural strength of oven-fog-aged birch plywood bonded with Cascophen LT-67.

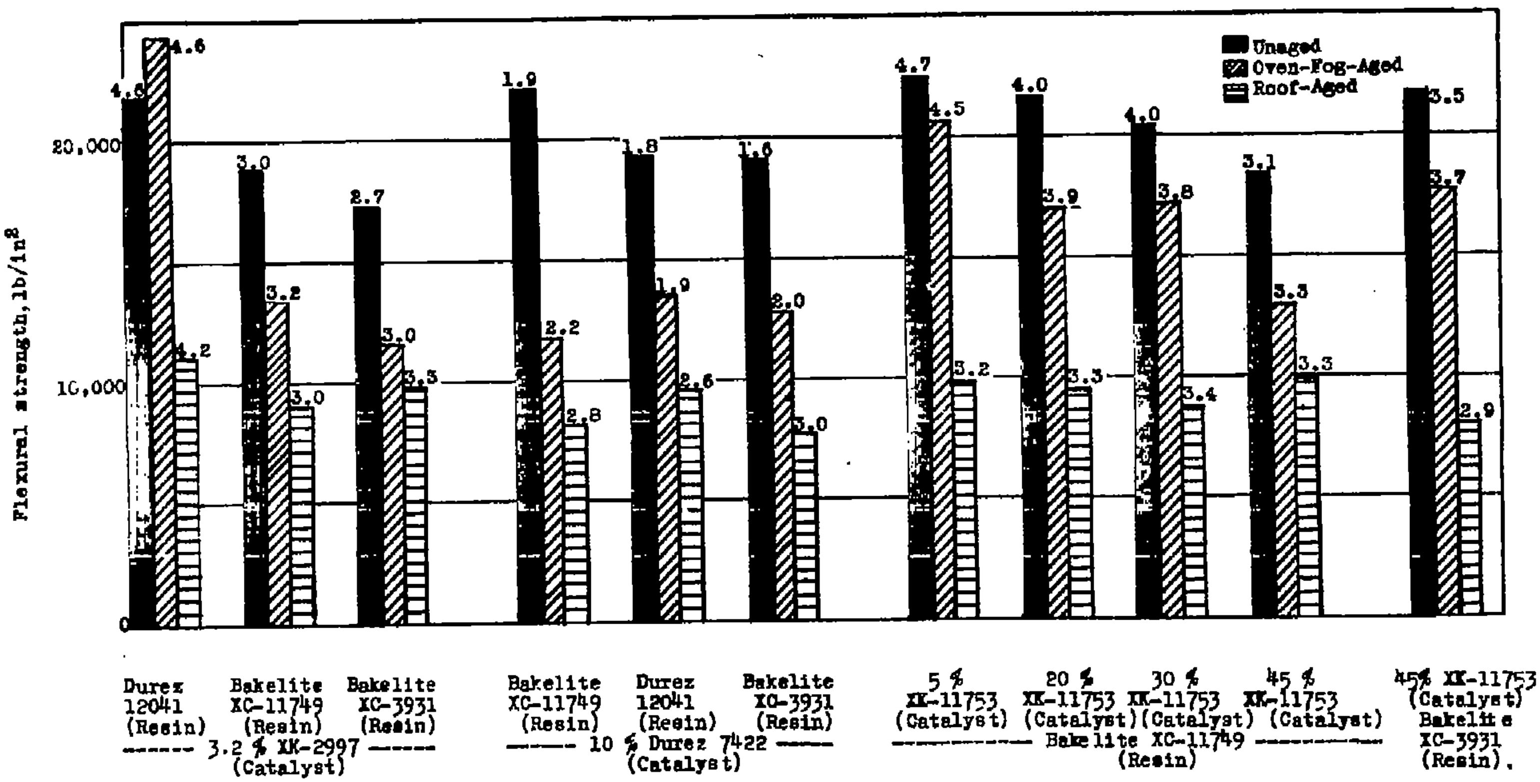

Figure 12.- Effect of various catalysts on flexural strength of birch plywood bonded with phenolic resins. (Number above each column indicates pH value of unaged panel.)

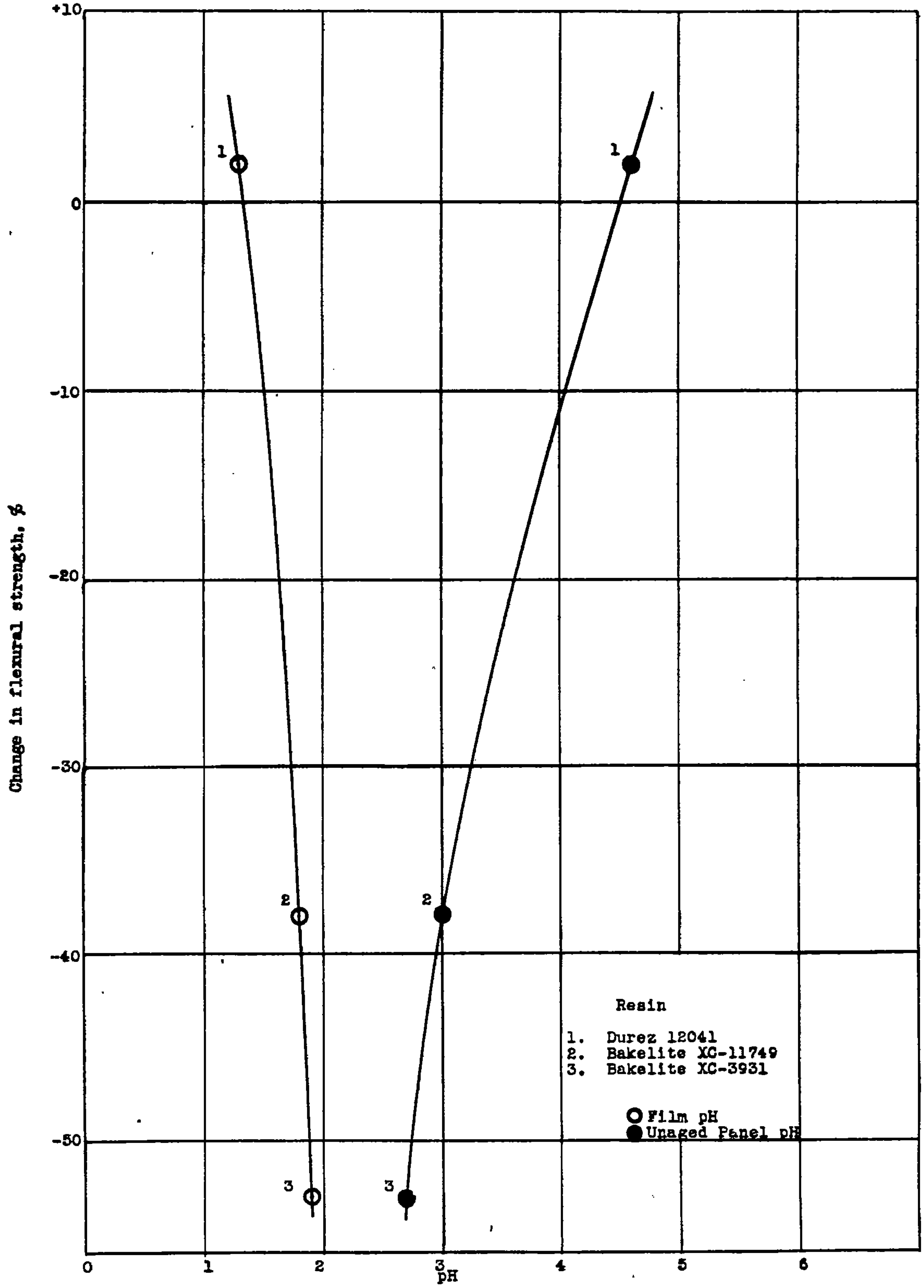

Figure 13.- Effect of catalyst (3.2% XK-2997) on flexural strength of oven-fog-aged birch plywood bonded with various phenolic resins.

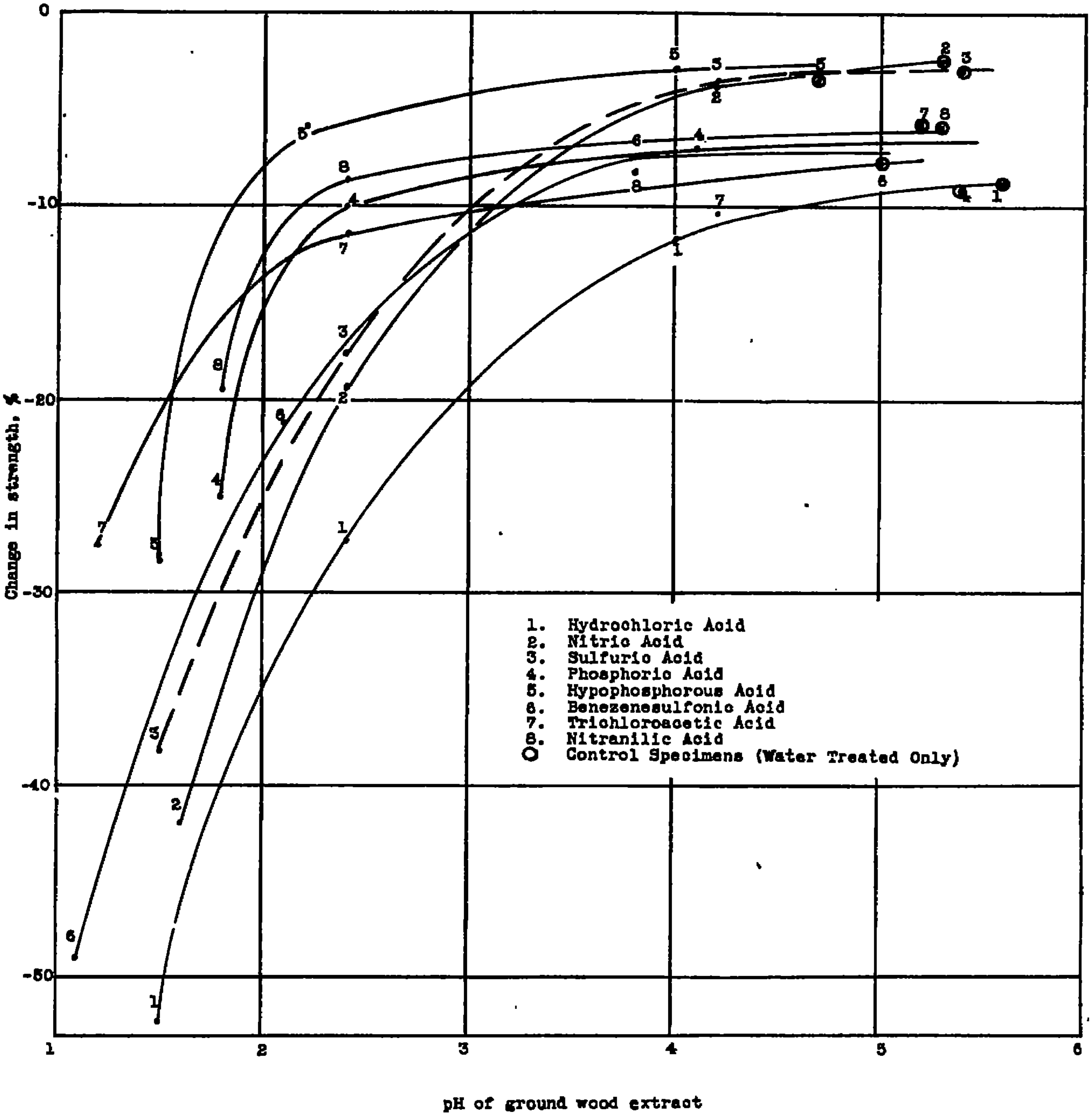

Figure 14.- Effect of various acids on flexural strength of birch wood.